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AIR FORCE HUMAN RESOURCES LABORATORY

DIGITAL AVIONICS INFORMATION SYSTEM (DAIS): MID-1980's MAINTENANCE TASK ANALYSIS

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20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

The fundamental objective of the Digital Avionics Information System (DAIS) Life Cycle Cost (LCC) Study is to provide the Air Force with an enhanced in-house capability to incorporate LCC considerations during all stages of the system acquisition process. The purpose of this report is to describe the technical approach, results and conclusions obtained from a Maintenance Task Analysis (MTA) conducted on a mid-1980s DAIS conceptual design configuration to identify and quantify support maintenance task requirements. This conceptual design configuration is one of two developed as bases for determining the maintenance support requirements of DAIS systems. They are described in AFHRL-TR-76-59, *Mid-1980s Digital Avionics Information System Conceptual Design Configuration*. The first is representative of an application of the DAIS principles of avionics integration to current avionics equipment. The second represents an application of DAIS principles to equipment expected to be operational in the

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mid-1980s.

An MTA was conducted on the current DAIS conceptual design configuration, AFHRL-TR-76-71, *Digital Avionics Information System (DAIS): Current Maintenance Task Analysis*. Its results provided a baseline for conducting the MTA reported here. The approach taken was to identify major system design changes and innovative support system capabilities projected to be available in the mid-1980s timeframe, along with major mechanization differences between the two conceptual designs. These were quantified in terms of their impact on maintenance support task requirements on the basis of an analysis of their impact on system reliability and maintainability (R&M) parameters. The calculation of R&M values for each task associated with the maintenance of the subsystems and line replaceable units of the mid-1980s DAIS conceptual design configuration represents a major portion of the effort covered by this report.

Three areas having significant impact on maintenance requirements were studied in some detail. First the impact of the DAIS architecture in terms of system reliability was quantified in terms of the demand on the maintenance system. Then two major innovations in system support capability, projected to be available in the mid-1980s timeframe, were evaluated in terms of their impact on the maintainability of the DAIS avionics. The first of these was the implementation of a central integrated test system (CITS) for on-board testing, flight reconfiguration, and flightline troubleshooting. The second was the use of consolidated support equipment (SE). Results indicate that the mid-1980s DAIS configuration with CITS and consolidated SE should yield a 47% reduction of total direct maintenance manhour requirements when compared with a conventional avionics suite.

The result of this mid-1980s DAIS MTA have been incorporated into a computerized mid-1980s DAIS data bank. It will be integrated into the overall LCC modeling system and associated data banks to be provided as a final product of the DAIS LCC Study.

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SUMMARY

BACKGROUND

The Digital Avionics Information System (DAIS) life cycle cost (LCC) study consists of a combination of Air Force Human Resources Laboratory (AFHRL) in-house and contractor efforts. This technical report is the third in a series which reports the overall study efforts. The output products of the study will consist of technical reports, data banks, and computer programs which will, in their totality, provide the elements for the DAIS LCC modeling system, the methodology for its use, and a description of the manner in which the results were obtained. A list of these products in the order of their delivery is as follows:

1. Mid-1980s Digital Avionics Information System Conceptual Design Configuration (technical report), AFHRL-TR-76-59
2. Current DAIS Maintenance Analysis Data Bank (data bank)
3. Digital Avionics Information System (DAIS): Curren Maintenance Task Analysis (technical report), AFHRL-TR-76-71
4. Mid-1980s DAIS Maintenance Analysis Data Bank (data bank)
5. Digital Avionics Information System (DAIS): Mid-1980s Maintenance Task Analysis and System Support Impact (technical report)
6. Mid-1980s DAIS Support Equipment Maintenance Data Bank (data bank)
7. Reliability and Maintainability Model (computer program)
8. Reliability and Maintainability Model (technical report)
9. Historical Data Bank (data bank)
10. Theoretical Data Bank (data bank)
11. Training Model (computer program)
12. Training Model Data Bank (data bank)
13. Training Model (technical report)
14. Cost Data Bank (data bank)
15. Modeling System Compatibility and Potential (technical report)

Maintenance analyses (MAs) were performed on conceptual design configurations of present day and mid-1980s close-air-support (CAS) applications of the DAIS principles of avionics integration, each of which incorporates the technology and equipment availability of its respective timeframe. The purpose was to develop reliability and maintainability (R&M) parameters and to identify and quantify support maintenance task requirements. The first MA was reported in AFHRL-76-71, Digital Avionics Information System (DAIS): Current Maintenance Task Analysis. The second is the subject of this report.

APPROACH

In conducting this MA, it was recognized at the outset that the two conceptual design configurations (i.e., current and mid-1980s DAIS) while superficially different, are functionally quite similar. That is, many of the same functions are provided by both suites; albeit their mechanizations are somewhat different. Thus the decision was made to conduct this MA on a functional basis; i.e., identify the major mechanization differences between the two design configurations, and quantify the impact that these differences will have on maintenance of the subsystems and line replaceable units (LRUs) of the mid-1980s DAIS conceptual design configuration.

Two major innovations in system support capability, projected to be available in the mid-1980s timeframe, are expected to afford a positive impact on the maintainability of avionics in general and DAIS integrated avionics in particular. The first is the implementation of a central integrated test system (CITS) for on-board testing, in-flight reconfiguration, and flightline troubleshooting. The second is the use of consolidated support equipment (SE): some completely automatic, some semi-automatic, some manual. The impact of each is described separately and then combined to give overall R&M values for each LRU and subsystem. These values are presented as figures of merit (FOM). They provide rankings for the 32 subsystems within the mid-1980s DAIS conceptual design configuration, such that "high driver" subsystems can be identified in terms of their demand on the maintenance system.

RESULTS AND CONCLUSIONS

Evaluation of support maintenance resource requirements indicated that the mid-1980s DAIS configuration with a CITS and consolidated SE should result in a 47 percent reduction of total direct maintenance manhours when compared with a conventional non-DAIS

avionics suite. The total reduction can be traced to a 30 percent reduction due to the basic mid-1980s DAIS architecture plus an additional 17 percent reduction due to the CITS and consolidated SE. In addition, an evaluation was made of the potential impact of the mid-1980s DAIS configuration on the overall service availability of a CAS avionics suite. The results indicate a 74 percent improvement when the mid-1980s DAIS configuration was compared with a conventional non-DAIS avionics suite.

The R&M parameters calculated for each task associated with the maintenance of the subsystems and LRUs of the mid-1980s DAIS configuration were incorporated into a data bank. The information included and its format provide the following capabilities:

1. Drive the Air Force Human Resources Laboratory maintenance manpower modeling system (MMMS) to determine the detailed utilization of resources in maintaining the mid-1980s DAIS conceptual design configuration.

2. Provide R&M figures of merit for each subsystem in the mid-1980s DAIS conceptual design configuration to allow an assessment of the major system problem areas in terms of operational readiness and operation and maintenance (O&M) costs.

3. Provide inputs to the maintenance manpower training model and reliability and maintainability model being developed within the DAIS LCC study.

PREFACE

This technical report is the third of a series of reports under Contract No. F33615-75-C-5218, "DAIS Life Cycle Costing Study" which, in combination with present Air Force capabilities, will provide the means to assess the life cycle cost impact of the operational implementation of the digital avionics information system.

The study was directed by the Advanced Systems Division, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, Ohio. It was performed under Air Force Avionics Laboratory Program Element 63243F, "Digital Avionics Information System", Project 2051. Project 2051, "Impact of DAIS on Life Cycle Costs", is jointly managed by the Air Force Human Resources Laboratory, Air Force Avionics Laboratory, and Air Force Logistics Command. Contract funds were provided by the Air Force Avionics Laboratory. The DAIS Program Manager is Lt. Col. Robert A. Dessert. The Air Force Human Resources Laboratory Project Scientist is Major Duncan L. Dieterly. The Air Force Logistics Command Project Officer is Captain Ronald Hahn. The latter two are DAIS Deputy Directors.

This research effort is documented under Work Unit 20510001, "DAIS Life Cycle Costing Study". Mr. H. Anthony Baran is the Work Unit Scientist and Air Force Contract Monitor. The contractor Program Manager is Mr. Herbert E. Engel.

The authors wish to extend their appreciation to the many people within the Government and private industry who contributed their time and expertise throughout the course of this research. Too numerous to mention by name, it must be sufficient to note that considerable assistance was rendered by: The DAIS engineering staff; personnel at the San Antonio and Oklahoma City Air Logistics Centers; Air Force Logistics Command Headquarters; Aeronautical Systems Division; personnel at Tactical Air Command Headquarters; the F-15 System Project Office; avionics maintenance personnel attached to the 509th Bomb Wing, Pease AFB, the 1st Tactical Fighter Wing, Langley AFB, and the 354th Tactical Fighter Wing, Myrtle Beach AFB; various organizations within the U. S. Navy including the Naval Air Systems Command Headquarters, and the A-7E Program Manager's Office.

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1. INTRODUCTION

The research described in this report was conducted to develop data required to assess the potential impact of the DAIS concept of avionics integration on Air Force system support functions. It consisted of a detailed analysis of the maintenance characteristics of present day avionics equipment and a systematic evaluation of the ways in which the DAIS concept might bring about change within a mid-1980s operational environment. Results, although based on one of a number of possible conceptual design configurations for a DAIS application, may be accepted as typical of what might be expected within the guidelines of the stated assumptions. They constitute a hybrid product of historical experience and engineering judgment which, at this time, represent the best that can be achieved until more engineering development data is available describing a specific DAIS implementation.

DAIS ADVANCED DEVELOPMENT PROGRAM

The DAIS concept has the potential of bringing substantial benefits to system reliability and cost because it provides: (1) an enhanced ability to modify software rather than hardware to meet new mission requirements, (2) an opportunity for adding new sensors and new capabilities to the system without rewiring the aircraft, (3) a potential means of incorporating modular or common equipment designs on different types of aircraft, (4) an improved testing capability through the introduction of a simplified central integrated test system, and (5) the potential for improved reliability through the planned use of redundancy at the subsystem, equipment, and component levels.

To capitalize on this potential, the U.S. Air Force established a DAIS advanced development program (DAIS ADP) in July 1973. The Air Force Avionics Laboratory (AFAL) is the lead agency and is coordinating the efforts of AFAL, the Aeronautical Systems Division, the Aerospace Medical Research Laboratory, the Air Force Flight Dynamics Laboratory, the Air Force Armament Laboratory, the Rome Air Development Center, the Air Force Logistics Command, and the Air Force Human Resources Laboratory. Their objectives are to demonstrate the DAIS concept on a functional basis and to develop: (1) an in-house cadre of skilled personnel who can perform preliminary design; (2) prepare specifications and standards for the four core elements of digital avionic systems, i.e., multiplex bus, processors,

control/displays, and software; and (3) develop techniques for the utilization of these core elements. To advance the time and degree of DAIS concept implementation, a DAIS integrated test bed and software test stand have been planned.

THE DAIS LIFE CYCLE COST STUDY

In order to realize the cost saving potential of DAIS, a method was required to quantify the costs at various stages of the system's life cycle. To this end, the Air Force Human Resources Laboratory (AFHRL) and Air Force Logistics Command (AFLC) were given the responsibility of performing a LCC analysis of a conceptual application of the DAIS concept of avionics integration. This responsibility included the development of improved means to assess system LCC.

In the past, LCC has been used primarily to track or predict operation and maintenance costs. Cost reductions have been effected by selecting logistic actions which minimize costs once a system has been acquired. In order to exercise maximum effect, LCC considerations must be introduced in the acquisition process early enough to impact the design of the hardware, the software, and their support system to avoid unnecessary cost. The DAIS LCC study is integrating a number of specialized models and data banks to form an LCC modeling system with an improved capability to assess LCC in the conceptual stages of weapon system development. Its initial application will be an assessment of the LCC impact of the DAIS concept of avionics integration. The DAIS MAs provide essential data to operate the system. The following outline describes the major tasks involved in establishing the modeling system and lends insight into data use and dependencies.

- Develop Conceptual Design Configurations for Current and Mid-1980s DAIS Avionics Suites. These configurations provide for the generation of data for all subsequent efforts in the modeling system development.

- Perform Maintenance Analysis. These provide detailed R&M data based on the conceptual design configurations. They also provide inputs for a reliability model, a training model, and a maintenance simulation model.

- Select Reliability Model. This model provides the capability to use the R&M parameter values to analyze the impact of various design configurations on system support requirements.

- Develop Training Model. This model selects a training approach and program based on mission effectiveness and cost considerations.

- Integration and Utilization. This involves the selection of appropriate models to compute acquisition and O&M costs, the integration of the various system models and the data banks to drive the LCC modeling system.

Two sets of requirements must be served in the O&M area: (1) those of the SE and manpower requirements portion of the DAIS LCC modeling system, and (2) those of the training analysis portion. The training analysis and subsequent design of the DAIS training model require detailed specification of the capabilities required of the maintenance manpower. This data falls in a category distinctly different from that of the data required for the SE and manpower portion of the DAIS LCC modeling system. It was therefore decided to use a two-step approach to meet these separate requirements. The first step documented in this report produced the results of an MA conducted along the lines of R&M, e.g., the numbers and types of manpower and support equipment required to maintain individual LRUs and subsystems. These requirements derive from the inherent reliability and maintenance characteristics of these equipments.

The second step, to be documented in a later report, will consist of an MA aimed at defining the specific knowledge and skill requirements for each type of manpower identified in the first step. Specification of these knowledge and skill requirements will form the basis for defining the DAIS impact on training requirements. The two-step procedure, while differing in its organization from what is traditionally considered a "classical" maintenance task analysis, has the virtue of providing greater visibility into individual elements of O&M cost.

OPERATION AND MAINTENANCE COSTS

The cost precipitating variables entailed in the operation and support of an avionics suite fall into three categories: (1) manpower (in terms of the numbers and skills required), (2) support equipment, and, (3) spare parts. The relationship of equipment R&M to O&M costs is depicted in Figure 1. The numbers and types of maintenance personnel are determined through a requirements analysis which takes into account the equipment design and performance requirements along

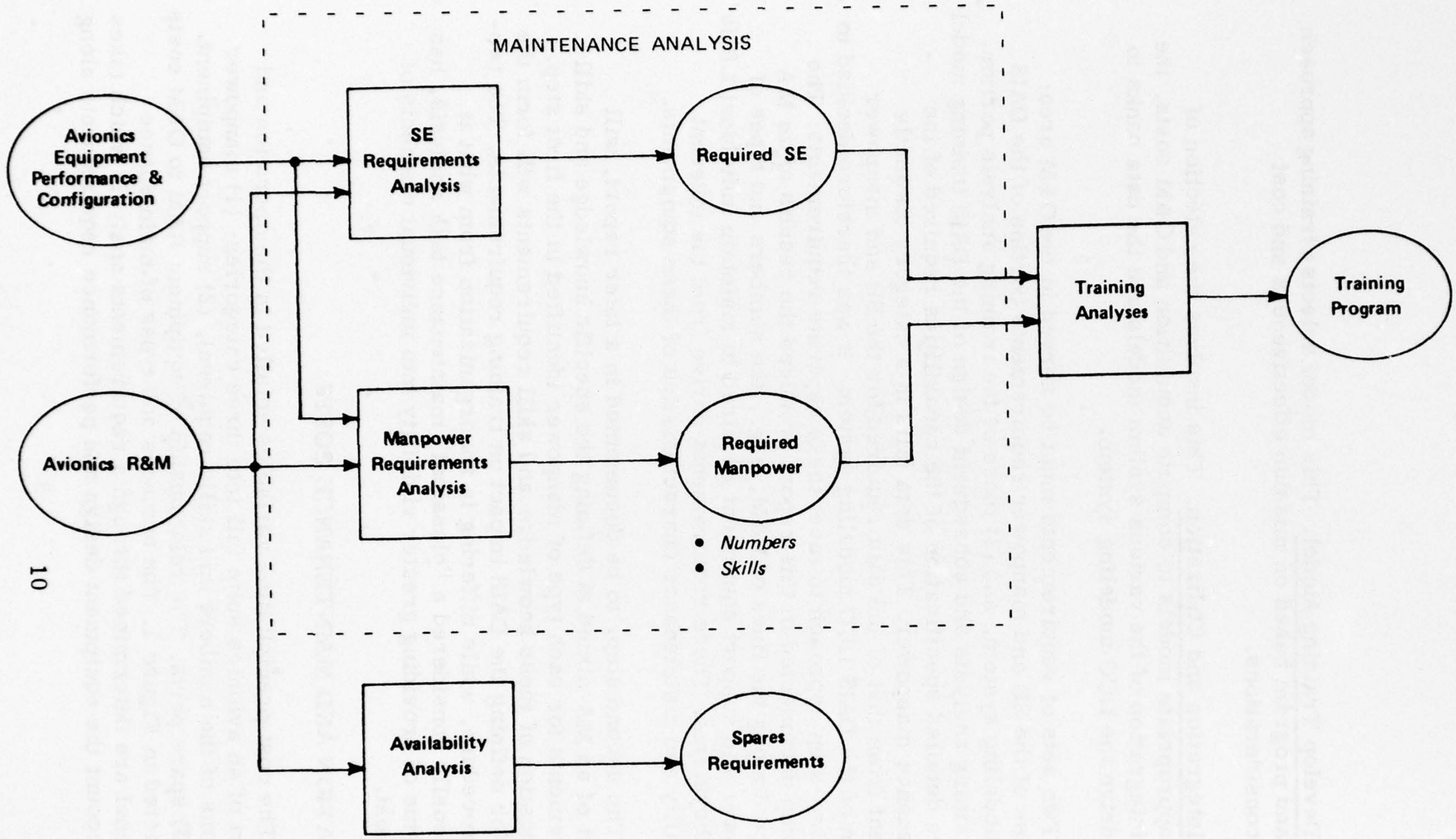


Figure 1 O&M COST ELEMENTS

with its R&M. The numbers and types of SE may be determined in an analogous fashion. However, since the manpower skills are provided by means of a training program geared to produce the required skills, the costs of training also play a significant role in determining the O&M cost component of LCC. Spares requirements may be determined through an analysis of the impact of the equipment R&M on the availability of the subsystems and line replaceable units on the flightline.

MID-1980s DAIS MAINTENANCE ANALYSIS

An overview of the four main steps accomplished in the mid-1980s DAIS MA is given in Figure 2. At the outset it was recognized that the current and mid-1980s DAIS configurations were functionally quite similar. It was therefore possible to build upon the current DAIS MA data bank by introducing perturbations due to system design changes and innovative support system capabilities projected to be available in the mid-1980s timeframe. Major mechanization differences between the current and mid-1980s DAIS configurations were identified and used to alter the R&M parameters to reflect the design impact. This procedure yielded a new set of R&M parameters representative of the mid-1980s DAIS architecture.

Using this new set of R&M parameters, the impact of two major innovations in support system capability were evaluated. The new capabilities projected to be available in the mid-1980s were a CITS and consolidated SE. The technical approach utilized to quantify these impacts is discussed in Section II. Results were then utilized to modify the R&M parameters computed on the basis of the mid-1980s DAIS architecture alone to produce an additional set of R&M parameters reflecting the impact of improvements in system support capability as well as that of the DAIS architecture.

REQUIREMENTS OF THE ANALYSIS

The maintenance analysis was performed to generate data specifically required to operate various components of the DAIS LCC modeling system. These are described in the following paragraphs. The set of requirements which they presented dictated a technical approach which deviates from that of a traditional maintenance task analysis in that it is oriented more toward defining the requirements of generic maintenance actions than toward the analysis of individual tasks.

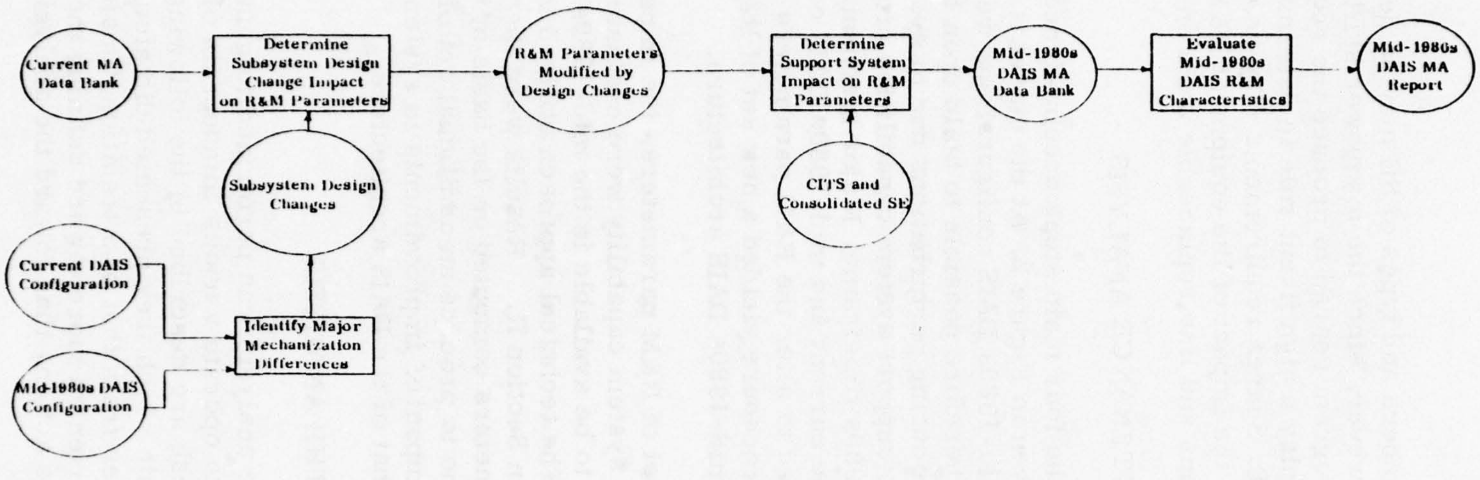


Figure 2 OVERVIEW OF MID-1980s DAIS MAINTENANCE ANALYSIS

Reliability and Maintainability Model

The R&M model is an important module in the overall DAIS LCC modeling system, and it can be used independently in a stand-alone mode. As part of the overall system, the primary function of the R&M model is to provide inputs to the logistics support cost model and the training model. When used in the stand-alone mode, the R&M model provides a means for analyzing the R&M impact of various avionics design configurations on system support requirements. This flexibility in the modeling system can be used whenever comparisons between competing inventoried equipments, modified versions of equipments, and equipments in various stages of their development are required. The R&M model employs a figure of merit concept to aggregate the detailed data and (1) make comparisons of resources required on a total system, subsystem, or LRU basis and (2) identify "high drivers" or problem areas in terms of resource requirements. In addition, the R&M model can be used to conduct sensitivity and tradeoff analyses. When high driver items are determined in terms of resource requirements, combinations of R&M parameters are perturbed to determine sensitivities. Then alternatives for achieving reduction in the resources required are identified.

Appropriate R&M data are required for these analyses. As a result of the MAs which have been conducted, R&M data has been generated for three representative configurations: the non-DAIS baseline, the current DAIS, and the mid-1980s DAIS. These provide system specific data inputs to the DAIS LCC modeling system. However, in subsequent use of the modeling system, new equipment specific R&M data can be used (provision is made to incorporate this data into the R&M data bank). There are three basic sources of this data. The best source will be from design and maintenance engineers familiar with the particular configuration under consideration. The next best estimates will be based upon R&M data from similar equipments. When the required data cannot be obtained from these sources, an additional analysis task is required. The purpose of this analysis task is to project R&M parameters based upon system characteristics. A functional relationship concept has been suggested to aid in this analysis task. The functional relationship concept assumes that significant system level design changes can be related to the R&M parameters. When functional relationships of this type are available they can be utilized to provide inputs to the R&M model portion of the LCC model. However, care must be taken to insure that proper confidence limits are included to avoid misinterpretation of the overall LCC model outputs.

Logistics Support Cost Model

The DAIS LCC modeling system will use a modified logistics support cost (LSC) model to compute the LSC portion of LCC. The LSC model presently under consideration was developed by the Air Force to estimate support costs expected to be incurred by adopting a particular system design for a weapon system. It is used to compare and discriminate among design alternatives where a determination of relative cost differences will suffice.

Comprised of data elements and mathematical equations, each of which describes a portion of the resources required for an operating logistics system, it is exercised by summing the following costs described in the <u>Logistics Support Cost Model User's Handbook</u>:

1. Initial and replacement line replaceable unit spares costs
2. On-equipment maintenance costs
3. Off-equipment maintenance costs
4. Inventory entry and supply management costs
5. Support equipment costs
6. Personnel training and training equipment costs
7. Management and technical data costs
8. Facilities costs
9. Fuel consumption costs
10. Spare engine costs

Modifications will include: (a) limiting the model's applicability to avionics; and (b) changes made necessary due to new capabilities provided by the DAIS concept. Table 1 shows the inputs required by the LSC model and the manner in which that data is provided by the MA.

Table 1 INTERFACE BETWEEN LSC MODEL AND MA

LSC In[illegible]	MA Output Provided
No. of LRUs pe[illegible] su[illegible]	Direct output of MA data banks
No. of a given LRU per subsystem	Direct output of MA data banks
No. of SE end items	Direct output of MA data banks
Utilization rate for SE	Equivalent to the mean time to repair (MTTR) or a portion thereof for each maintenance task. MTTR is a direct output of the MA data banks.
Fraction of operational failures repairable at flightline	Direct output of MA data banks
Mean flying time between maintenance actions	Failure clock in MA data banks is in terms of mean sorties between maintenance actions (MSBMA). Conversion is in terms of flying hours per sortie.
Fraction of removals repaired at base level (per LRU)	Direct output of MA data banks
Mean time to repair per LRU at base level	Direct output of MA data banks
Mean time to repair per subsystem at flightline	Direct output of MA data banks
Mean time to remove and replace LRUs at the flightline	Direct output of the MA data banks
Fraction of LRU removals sent to depot for repair	Direct output of the MA data banks
Scheduled maintenance man hours and scheduled maintenance intervals	Scheduled maintenance is a small fraction of total avionics maintenance. Fractional increments will be added to unscheduled maintenance values (as appropriate) to account for this.

DAIS Training Model

The DAIS training model will provide a capability to evaluate alternative training approaches and training programs for DAIS maintenance. It will provide a means to ascertain the impact of the DAIS on training procedures and also to analyze options or innovations in training procedures which implementation of the DAIS may offer. Selection of the training program will be based on tradeoffs among the equipment characteristics, manpower availability, mission effectiveness, and LCC.

Inputs which will drive the DAIS training model will include: descriptions of knowledge elements and skills needed in DAIS equipment maintenance; descriptions of the tasks performed in terms of criticality, difficulty, and frequency; available methods and media of instruction; and the costs associated with these various alternatives. The skill and knowledge inputs will result from a training analysis which will be part of the DAIS training model development. However, the training analysis uses the MA as a data source for the types of maintenance tasks required, their frequency, and the amount of manpower needed to perform the maintenance activities.

AFHRL Maintenance Manpower Modeling System

The AFHRL MMMS is a simulation model used to assess the combined effect of operations and support variables on maintenance manpower requirements and weapon system availability. The data required to operate it are: frequency of occurrence of a maintenance event; probability that a given task will be performed; type of task; time required to complete a task; manpower quantity, type, and skill level needed to perform a task; and test equipment required. A convenient representation of these data elements is the maintenance task network (MTN). A description of the MTN and the methodology for the synthesis of the DAIS MA data elements included in it appears in the following section.

II. MID-1980s DAIS MAINTENANCE ANALYSIS AND DATA BANK DEVELOPMENT

The mid-1980s DAIS MA builds upon previous work accomplished in the current DAIS MA, using its results as a baseline. The "on-equipment" and "off-equipment" maintenance tasks required to restore a subsystem or LRU to operable condition were, in most instances, the same and already modeled in existent maintenance task networks (MTNs). The first step of this maintenance analysis was, therefore, to identify the major mechanization differences between the current and mid-1980s DAIS conceptual design configurations. This permitted identification of the impact of the mid-1980s DAIS architecture on various R&M parameters of the avionics suite. Next the specific benefits of CITS and consolidated SE were assessed. This information was used to further modify the R&M parameters, many of which were already modified as a consequence of the mid-1980s DAIS architectural impact. R&M parameter modifications were then quantified in terms of the MTNs. Results were then incorporated in a computerized data bank. They reflect the combined impact on maintenance task resource requirements of both the mid-1980s DAIS architecture and the improved system support capability expected to be available in the mid-1980s timeframe.

Results of the above process (maintenance task resources required to support the mid-1980s DAIS conceptual design configuration) are: (1) number and types of manpower; (2) support equipment; and (3) time required for both on-aircraft and off-aircraft maintenance actions.

Comparisons were made with a conventional non-DAIS avionics suite. They indicated a potential reduction of 47 percent in overall direct maintenance manhour requirements in favor of the DAIS. An assessment of the total impact of the mid-1980s DAIS configuration (to include the use of CITS and consolidated SE) on the overall service availability of a CAS mission avionics suite indicated a 74 percent improvement in favor of the DAIS when compared with a conventional non-DAIS CAS mission avionics suite. The following portions of this section describe more fully each step in the conduct of the mid-1980s DAIS MA.

MAINTENANCE TASK NETWORKS

The MTN is a convenient representation of type and order of maintenance tasks that have to be accomplished to return a subsystem to operable condition. The "on-equipment" tasks are accomplished at the organizational level and pertain to the entire subsystem. The "off-equipment" tasks are shop tasks on the LRUs and are usually conducted at the intermediate maintenance level. An example of a simplified MTN is given in Figure 3.

The maintenance process is initiated by a discrepancy report or indication on the part of the aircrew or maintenance personnel that a malfunction exists. Whether this proves to be an actual failure or is a human (or equipment) error which will later result in a "cannot duplicate" (CND) is important from the point of view of the MA since both result in a demand for maintenance resources. The subsystem failure frequency is therefore based on these discrepancy reports which trigger subsequent maintenance tasks on the flightline. These possible flightline maintenance tasks are:

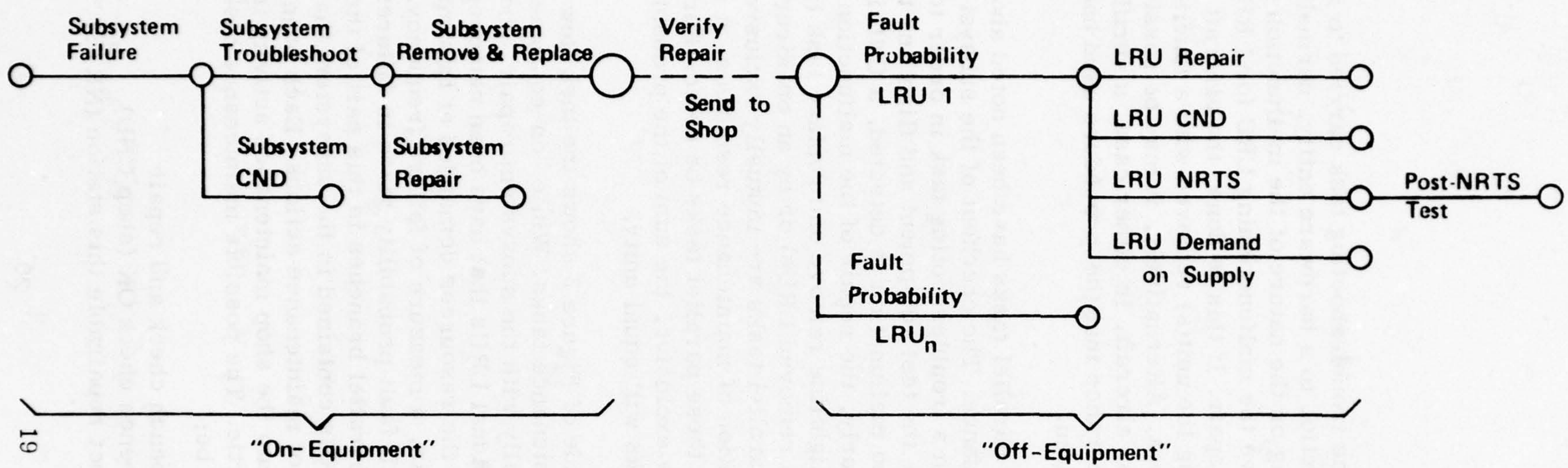
a) Troubleshooting
b) Troubleshooting, cannot duplicate discrepancy
c) Remove and replace
d) Minor repair
e) Verify replacement correcting discrepancy
f) Verify minor repair correcting discrepancy

These tasks, as we have defined them, are generic maintenance events consisting of one or more maintenance functions (i.e., adjust, align, calibrate, troubleshoot, inspect, operate, remove/install, repair, service, etc.). Therefore, they are not tasks by the definition that the task analyst uses when he is evaluating behavioral requirements associated with the repair process. Although somewhat gross, the tasks used in this MA are sufficient for the purpose of assessing support requirements in the early stages of the systems acquisition process. This is a logical approach since these tasks represent the practical limits of applying the less-detailed data that is available in these early stages.

The initial maintenance task is to set up the necessary test equipment and power sources at the flightline and exercise the subsystem that has a discrepancy. If in fact a failure has occurred, a troubleshooting task will take place in order to locate the cause of the malfunction. In some instances, the apparent failure cannot be duplicated and the maintenance activity will terminate as a CND disposition.

Figure 3

SIMPLIFIED MAINTENANCE TASK NETWORK
(Indicating Only the Task Flow)



The flightline troubleshooting task carried to its conclusion isolates the malfunction to a hardware entity, normally a line replaceable unit. Depending on the nature of the malfunction it may be necessary to remove the malfunctioning LRU (or LRUs) and send it to the field shop for repair. If this is done, the aircraft is put back into service by replacing the unit(s) removed with a functioning LRU(s) from the supply stock. Alternatively, it may be possible to effect the needed repair on the aircraft. In either case, a verification task is used to provide assurance that the procedure used has, in fact, corrected the problem.

Two sets of parallel tasks have been noted above for the "on-equipment" maintenance. The checkout of the subsystem may, in the first case, result in a troubleshooting task in order to locate a malfunction detected by the test equipment and flightline technician. On the other hand, if no malfunction is detected, a CND is recorded as the outcome. Similarly, the repair of the malfunction may be accomplished through a flightline remove and replace task (and subsequent shop activity on the removed LRUs) or by an on-aircraft repair task. In each case, the parallel tasks are *mutually exclusive events*. In terms of the utilization of maintenance resources, it is necessary that the probabilities of these parallel tasks be noted. Further, since the events are mutually exclusive, the sum of the probabilities of each pair of parallel tasks will equal unity.

The right side of Figure 3 shows the task flow for "off-equipment" or shop maintenance tasks. While "on-equipment" maintenance is concerned basically with the subsystem repair, shop maintenance deals with the individual LRUs that have been removed from the aircraft. Determining the resources demanded at this maintenance level requires, once again, a measure of failure frequency. This is indicated by the LRU fault probability given in failures per sortie. The number (n) of parallel branches in this part of the MTN is equal to the number of LRUs contained in the subsystem that have any significant number of maintenance actions. Each branch indicates the entry of that LRU into the shop maintenance activity in terms of its failure rate per sortie. The possible maintenance tasks that can be conducted will then be:

a) LRU bench check and repair
b) LRU bench check OK (shop CND)
c) LRU not repairable this station (NRTS)

It may be noted that shop tasks, as defined, are somewhat broader in scope in terms of possible maintenance functions than flightline tasks. The LRU bench check and repair task encompasses a troubleshooting activity which detects a malfunction in that LRU and a subsequent part replacement, calibration, adjustment, or whatever additional functions are necessary to bring the LRU back to full operating status. The CND result which sometimes occurs is due to the fact that fault location at the flightline is imperfect and leads to the wrong LRU being sent to the shop. Often the flightline procedures can only isolate the malfunction to a group of LRUs so that all have to be sent on to the shop. Such a circumstance would result in the reporting of a bench check and repair on the LRU that had actually failed with CNDs for the remaining units of the group. Another possible cause of shop CNDs stems from the operating and test procedures associated with certain pairs or groups of LRUs which have been mutually calibrated, in effect "married" to one another. When a malfunction appears to exist in one, the other or others must accompany it to the shop to assist in testing and possible subsequent recalibration. Here again, only the malfunctioning LRU will be shown as a bench check and repair unit. The others will be tallied as CNDs.

The NRTS disposition is used to describe the maintenance event which results in shipping a unit to another maintenance echelon where greater capability exists for certain types of testing and/or repairs. Usually this is the depot where more sophisticated test equipment and higher skill levels have been pooled. The units shipped may be either LRUs or shop replaceable units (SRU). If the shop has no capability to maintain a specific LRU it will be NRTS to depot. In other instances, repairs can be effected by removing and replacing malfunctioning SRUs which, in turn, cannot be serviced at that location. The SRUs will then be NRTS-dispositioned to the appropriate depot.

The MTN models the flow of the maintenance tasks and, therefore, provides a means to determine demand on the maintenance system. Each parameter in the MTN must be evaluated for a given avionics configuration in order to assess its maintenance resource requirements. The remainder of this section describes the manner in which these R&M parameters were quantified for the mid-1980s DAIS conceptual design configuration. These parameters include the subsystem failure rate and, by task, the following:

a) probability of occurrence
b) crew size
c) skill category
d) skill level
e) average time to complete
f) type support equipment required.

THE IMPACT OF SUBSYSTEM DESIGN CHANGES

The mid-1980s DAIS conceptual design configuration is basically an extension of the current DAIS configuration. It implements the effect of new technology and packaging improvements projected to be available in that timeframe. In order to evaluate the maintenance impact of these advances in avionics design, a composite analysis was undertaken at the system level using the results of the current MA as a point of departure. Where projected technology and packaging improvements appeared likely to significantly affect the R&M characteristics of the equipment, engineering judgment was combined with analysis of historical data to project and evaluate the impacts. The corresponding R&M parameter values were then changed accordingly.

Most of the avionics equipment selected for the DAIS conceptual application are presently configured such that DAIS partitioning to the LRU level effectively separates all sensor and core element functions without the necessity of extending the partitioning process to the shop replaceable unit level. However, eleven subsystems of the current DAIS configuration contain LRUs which perform both sensor and core functions. These eleven subsystems are identified by an asterisk in Table 2. Engineering analyses revealed that, in some cases, potential benefits could accrue if the applicable LRUs of these subsystems were partitioned to the SRU level and/or transferred to the core. Therefore, seven of these LRUs were partitioned to the SRU level and six other LRUs were transferred to core. The mid-1980s DAIS sensor and core configuration was then defined based upon these new assignments.

Additional engineering analyses were required to determine the resulting impact on sensor and core reliability, redundancy, and processing requirements. Engineering judgment based upon the degree of elimination and/or transferral of failure modes was used to estimate the resulting impact on sensor reliability. The required number of each type of core element is the same for both the current DAIS and the mid-1980s DAIS configurations. Consequently, the core element R&M characteristics are identical for both configurations.

Table 2

IMPACT OF MID-1980s DAIS PARTITIONING
ON SUBSYSTEM RELIABILITY VALUES

	Mean Sorties Between Maintenance Actions		
	Mid-1980s w/o CITS/SE	Current DAIS	Non-DAIS Baseline
Flight Instruments	32	32	32
Navigation Instruments	400	400	400
HF Radio	28	28	19
VHF-FM Communications	41	41	38
*Data Link	217	71	42
*UHF Radio	36	32	20
*Automatic Direction Finder	184	164	143
Intercom Set	86	86	86
*IFF Transponder	320	68	48
Speech Security	70	70	48
*Heading Mode	586	72	44
*TACAN	35	24	23
*Instrument Landing System	123	63	60
*Radar Altimeter	28	21	21
Radar Beacon	64	64	45
*Forward Looking Radar	21	21	10
*Air Data Computer	76	44	44
*Inertial Measurement	16	11	10
Forward Looking Infrared	20	20	20
Laser Target ID	18	18	18
RHAW	60	60	39
Infrared Tail Warning	33	33	33
Camera	677	677	677
Electronic Display	1110	1110	-
Special Purpose Display	39	39	-
Display Controls	89	89	-
Mass Memory Unit	58	58	-
Multifunction Controls	699	699	-
Dedicated Controls	712	712	-
Processor	22	22	-
Bus Control Interface Unit	129	129	-
Remote Terminal Unit	57	57	-
Tactical Bombing Computer	absorbed by core		15
Head-Up Display	absorbed by core		14
Projected Map Display	absorbed by core		56
Average MSBMA = $\overline{MSBMA}$	1.52	1.31	1.06

The reliability impact of the repartitioning was described in terms of the MTN reliability parameter: mean sorties between maintenance action (MSBMA) per subsystem. The MSBMA is a measure of the demand placed on both the flightline and shop portions of the maintenance system. Resulting values of MSBMA are summarized in Table 2 for each of the configurations studied; i.e., the non-DAIS as a baseline, the current DAIS conceptual design, and the mid-1980s DAIS conceptual design.

Values for the non-DAIS baseline configuration, shown in Table 2, are taken directly from Air Force and Navy maintenance data collection (MDC) systems data. Values for the current DAIS configuration reflect the results of partitioning those sensors to transfer the processing and control/display (C/D) functions to core elements. The bus control interface units (BCIU) and remote terminal units (RTU) are also part of the core element structure used to couple the processors and sensors, respectively, to the multiplex bus. The values of MSBMA for the BCIU, RTU, and processor were determined from the DAIS core configuration. Values for the mid-1980s configuration show the impact of design modifications including the specification of the new subsystems and their partitioning to the SRU level. The total system value, $\overline{MSBMA}$, is given at the bottom of each column. Overall comparisons between the three system configurations can thus be made with respect to their total demand on the maintenance system in terms of $\overline{MSBMA}$.

Such a comparison shows one of the significant impacts of configuring avionics according to DAIS principles. Partitioning the avionics of the non-DAIS baseline design configuration indicates an improvement of approximately 24 percent in $\overline{\text{MSBMA}}$. This results from the simplification of the resulting sensor hardware and the accomplishment of the processing and C/D functions by means of highly reliable, standardized digital modules. The partitioning of subsystems incorporating technology of the mid-1980s subsystems should result in an additional improvement of approximately 20 percent over the current DAIS configuration for a total improvement of approximately 44 percent. The additional benefits of improved support system capabilities projected to be available in the mid-1980s timeframe should yield a further improvement. The additional impact of that improvement is examined next.

SUPPORT SYSTEM IMPACT IDENTIFICATION

Two major innovations in system support capability, projected to be available in the mid-1980s timeframe, are: (1) the implementation of a CITS for on-board testing, flight reconfiguration, and flightline troubleshooting; and (2) the use of consolidated SE. These capabilities will surely impact the maintenance of DAIS avionics. Both serve as forcing functions on maintenance requirements and were modeled in terms of the effectiveness of tests performed. (The parameters used to describe test effectiveness were: time to perform the test, and the CND rate.) The improved test effectiveness and associated manpower impact were translated into maintenance task resource requirements via an assessment of their impact on the MTN parameters that describe each task. This entailed a systematic analysis to quantify changes in the values of the MTN parameters due to improved test effectiveness and the potential manpower impacts of each support system capability.

The procedure used to analyze the impact of these innovative capabilities is somewhat involved. The first two steps, addressing the identification of impacts are described in the following pages. The reader wishing to dispense with the details of the methodology may, at this point, turn to page 39 for a description of the third step which addresses the quantification of the impacts identified in Steps 1 and 2.

Support System Characterization

The objective of step 1 of impact identification is to characterize the support system in terms of the effectiveness of tests performed using the consolidated SE and CITS. The consolidated SE concept investigated was similar to that under development for the F-15 program. It was postulated that all mid-1980s DAIS LRUs will be tested by six consolidated test stations, each capable of testing specified LRUs. Mid-1980s test station design will probably be modular, allowing degraded modes of operation. Therefore, shut-down of the entire station would be necessary only in the event of failure within an element common to several or all modules, e.g., power supply, central processor, etc. When consolidated SE was compared with avionics SE in use today, it was determined that the core element test times could be reduced by 20 percent. Sensor task times will probably remain unchanged. Consolidated SE also has the potential to reduce the number and skill level of maintenance personnel that perform the equipment bench checks. This impact will be addressed by step 2.

CITS offers the potential for improved test capability in terms of fault detection and isolation, and test repeatability. It is a software system which uses existing built-in test (BIT) built-in test equipment (BITE), and the DAIS processors to perform tests not practical in today's environment. It also provides a recording of the results of the inflight testing which can be used by the maintenance personnel to reconstruct the situation at the time of a failure or discrepancy report. Thus a more total picture can be obtained of what, if anything, actually failed, and what may have caused the failure or discrepancy report.

Among the types of tests which can be improved by CITS are: go/no go, rate of change, fixed input, deviation from average, voting, innovation, and demand. Go/no go tests can be either active or passive. In either case the test measures an output, compares it with a predetermined reference value, and a decision is made whether the equipment tested is operating properly. Rate of change tests measure the time derivative of a signal. This may be accomplished by determining the difference between consecutive signal values obtained over a specified time interval. Fixed input tests use constant, known aircraft flight parameters as an input to determine the reaction of the avionics. Deviation from average tests use the computation of an average value of a signal or data item and compare instantaneous values against it. The comparisons are normally conducted on a short-term basis, i.e., the instantaneous value is compared to the data

average of the previous time interval. Voting or correlation type tests compare data outputs of comparable subsystems or LRUs. Position outputs derived from the inertial system, TACAN, UHF automatic direction finder (UHF/ADF) are examples of outputs which can be used in such a test. If significant differences cannot be reconciled within the specified error tolerances of the individual equipments, a decision is made as to which one is in error.

For some subsystems Kalman filtering is utilized to obtain best estimates of parameters based upon a combination of inputs. When a Kalman filter is present in the central processor, innovation testing can be utilized. The innovation is defined to be the difference between the Kalman predicted observation and the actual observation. The innovations can be monitored over time to provide indications of impending failures.

Demand tests are the operator-generated repetition of an individual or series of available tests. These tests include a go/no go diagnostic test routine to fault isolate to an LRU. Fully exploiting the capabilities of CITS and DAIS will permit the incorporation of additional active tests at the LRU level, as well as tests to isolate to the SRU level. These will allow implementation of maintenance concepts in which a greater portion of the maintenance is conducted on the flightline. However, no attempt was made at this time to postulate either this design or its effect on the maintenance parameters.

To complete the characterization of CITS in terms of improved test capability, each subsystem and LRU was evaluated to determine applicable tests. Results are given in Tables 3 and 4 respectively. The improvements of CITS and consolidated SE allow also for reductions in spares and the number of maintenance personnel required to support the DAIS. Reduction in the number of required maintenance personnel is a fallout of the increased simplicity and comprehensiveness with which troubleshooting can be accomplished when a CITS is employed. The major impact of consolidated SE is in terms of the potential reduction in number and skill level of maintenance personnel that perform equipment bench checks.

The objective of the second step of impact identification is to determine the specific location of impacts in terms of the MTNs which model the maintenance task sequences and resource requirements. The total impact is comprised in two parts: (1) the demand on the maintenance system and (2) the number and skill level of maintenance personnel required to meet this demand.

TABLE 3

CITS IMPACT ANALYSIS*

SUBSYSTEM EVALUATION

Subsystem WUC	Function	Go/ No-Go	Rate of Change	Fixed Input	Deviation from Average	Voting	Demand	Innovation
61A00	HF Radio	X	–	–	X	–	X	–
62A00	VHF-FM Comm.	X	–	–	X	–	X	–
63510	Data Link	X	–	–	X	–	X	–
63A00	UHF Radio	X	–	–	X	–	X	–
63300	UHF/ADF	X	–	X	X	X	X	X
64A00	IC	X	–	–	–	–	X	–
65A00	IFF Transponder	X	–	–	X	–	X	–
69A00	Speech Security	X	–	–	–	–	X	–
71B00	TACAN	X	X	X	X	X	X	X
71C00	Marker Beacon	X	X	X	X	–	X	X
72A00	Radar Altimeter	X	X	X	X	X	X	X
72B00	Radar Beacon	X	X	–	X	–	X	X
73A00	FLR	X	–	–	X	–	X	–
73C00	Air Data Computer	X	X	X	–	X	X	X
73F00	IMS	X	X	X	X	X	X	X
76E00	RHAW	X	–	–	–	–	X	–
77A00	Strike Camera	X	–	–	X	–	X	–
74H00	Laser Target ID Set	X	–	–	X	–	X	–
74G00	FLIR	X	–	–	X	–	X	–
76L00	IR Tail Warning	X	–	–	X	–	X	–
7WA00	Elect. Display Grp.	X	–	–	–	–	X	–
7WB00	HUD-VSD	X	–	–	–	–	X	–
7WC00	Display Controls	X	–	–	–	–	X	–
7WD00	Mass Memory Unit	X	–	–	–	–	X	–
7XE00	Multi Function Cont.	X	–	–	–	–	X	–
7XF00	Dedicated Cont.	X	–	–	–	–	X	–
7YA00	Processor	X	–	–	–	–	X	–
7ZA00	BCIU	X	–	–	–	–	X	–
7ZB00	RTU	X	–	–	–	–	X	–

* x's represent those tests that are judged applicable to the specified subsystem

Table 4 CITS IMPACT ANALYSIS*

LRU Evaluation

Subsystem	LRU	Go/ No Go	Rate of Change	Fixed Input	Dev. from Ave.	Voting	Demand
HF	Receiver/Transmitter (R/T)	x	-	-	x	-	x
	Amplifier/Power Supply (PS)	x	-	-	x	-	x
	Antenna Coupler	x	-	-	-	-	x
	Variable Capacitor	x	-	-	-	-	x
VHF FM Comm.	R/T	x	-	-	x	-	x
	Antenna Coupler	x	-	-	-	-	x
Data Link	R/T	x	-	-	x	-	x
	Mount & Antenna	x	-	-	-	-	x
UHF Radio	R/T	x	-	-	x	-	x
	Standing Wave Ratio (SWR) Indicator	x	-	-	-	-	x
	Diplexer	x	-	-	-	-	x
UHF-ADF	Relay Amplifier	x	-	x	x	x	x
	Antenna	x	-	-	-	-	x
	Receiver	x	-	-	-	-	x
Intercom (IC)	IC Set Control	x	-	-	-	-	x
	Station IC	x	-	-	-	-	x
	Audio Relay	x	-	-	-	-	x
IFF Transponder	R/T	x	-	-	x	-	x
Speech Security	Coder/Decoder	x	-	-	-	-	x
	Relay	x	-	-	-	-	x
TACAN	R/T	x	x	x	x	x	x
	Antenna Switch	x	-	-	-	-	x
Marker Beacon	Glideslope Receiver	x	x	x	x	-	x
	Localizer Receiver	x	x	x	x	-	x
	Antenna	x	-	-	-	-	x
Radar Altimeter	R/T	x	x	x	x	x	x
	Interference Blanker	x	-	-	-	-	x
	Antenna	x	-	-	-	-	x

*x's represent those tests that are judged applicable to the specified LRU.

Table 4 (continued)

Subsystem	LRU	Go/ No Go	Rate of Change	Fixed Input	Dev. from Ave.	Voting	Demand
Radar Beacon	R/T	x	x	-	x	-	x
	Antenna	x	-	-	-	-	x
Forward Looking Radar (FLR)	Antenna/Receiver	x	-	-	x	-	x
	Transmitter	x	-	-	x	-	x
	PS Programmer	x	-	-	-	-	x
Air Data Computer	Air Data Computer	x	x	x	-	x	x
Inertial Measurement Set (IMS)	Inertial Measurement Unit (IMU)	x	x	x	x	x	x
	PS Adapter	x	x	x	x	-	x
Radar Homing & Warning (RHAW)	Signal Processor	x	-	-	-	-	x
	Receiver	x	-	-	-	-	x
	Amplifier Detector	x	-	-	-	-	x
Strike Camera	Camera	-	-	-	-	-	-
	Camera Box	-	-	-	-	-	-
	Mount	-	-	-	-	-	-
	Electrical Control	x	-	-	-	-	x
Identification Target Set (ID)	Laser/EO/Gimbals	x	x	-	-	-	x
	Pod	x	-	-	-	-	x
Forward Looking Infrared (FLIR)	Infrared (IR) Receiver	x	-	-	-	-	x
	PS	x	-	-	-	-	x
	Optical Stabilizer - POD	x	x	-	-	-	x
IR Tail Warning	Search Track Scanner	x	-	-	-	-	x
Electronic Display Group	Multi Purpose	x	-	-	-	-	x
	Horizontal Situation Display (HSD)	x	-	-	-	-	x
Special Purpose Displays	Head-Up Display (HUD)	x	-	-	-	-	x
	Vertical Situation Display (VSD)	x	-	-	-	-	x

Table 4 (continued)

Subsystem	LRU	Go/ No Go	Rate of Change	Fixed Input	Dev. from Ave.	Voting	Demand
Display Controls	Modular Programmable Display Gen.	x	-	-	-	-	x
	Display Switch/Memory Unit	x	-	-	-	-	x
Mass Memory Unit	Electronic	x	-	-	-	-	x
	Magnetic Tape Transport Unit (MTTU)	x	-	-	-	-	x
	Control	x	-	-	-	-	x
Multi-function Controls	Keyboard	x	-	-	-	-	x
	Control Panels	x	-	-	-	-	x
Dedicated Controls	Power/Start-Up Panel	x	-	-	-	-	x
	Armament Panel	x	-	-	-	-	x
	Communications Panel	x	-	-	-	-	x
	Entry Keyboard	x	-	-	-	-	x
	Master Mode Panel	x	-	-	-	-	x
	Sensor Controller	x	-	-	-	-	x
	Sensor Controller Unit	x	-	-	-	-	x
Processor	Computer	x	-	-	-	x	x
	Maintenance Control Panel	x	-	-	-	-	x
Bus Control Interface Unit (BCIU)		x	-	-	-	-	x
Remote Terminal Unit (RTU)		x	-	-	-	-	x

Impact of CITS

The MTNs described earlier characterize maintenance requirements for different configurations of avionics. In order to assess the CITS impact, it is necessary to relate the potential for improved testing to these MTN parameters. The approach taken was to first define the potential CITS impact in general terms and then relate this impact to the specific MTN parameters.

Logically, any test attempts to identify failed systems as bad and operable systems as good. However, no test equipment is perfect. Hence, there are four possible outcomes of any test as illustrated in the truth Table 5.

Table 5
TRUTH TABLE FOR CITS TESTS

Actual System Status	
Operable	Failed
Good Bad	Good Bad

Test System Indication
(Test Outcomes)

Problems occur when the test equipment indicates that an operable system is bad or a failed system is good; i.e., the off-diagonal terms in Table 5. (The diagonal terms represent the desirable outcomes.) The major impact on maintenance task resources is when an operable system is judged bad by the test equipment. In this cast the system (or LRU) will appear in the MTN as a CND, either at the flightline (system level) or at the shop (LRU level). It should be noted that failed systems called good have an adverse impact on mission effectiveness since the aircraft will be flying with failed systems on board. Many of these may not be catastrophic failures but rather are exemplified by degraded performance or intermittent problems. Mission effectiveness requirements should be treated as a constraint when designing improved testing capability. However, the intent of this effort is to evaluate the impact on maintenance task resource requirements. Other consequences, such as impact on mission effectiveness are not investigated here.

Based upon the above observations, it is clear that CITS could beneficially impact flightline and shop CNDs and reduce manpower requirements at the flightline level of maintenance as a consequence of simplified testing. Since the maintenance task requirement parameters are coupled through the MTN and associated equations, the CITS impact on them can be isolated as follows. First, all the MTN parameters are evaluated for the mid-1980s DAIS configuration without CITS. Then the specific impacts of CITS on individual MTN probability of occurrence parameters are identified and quantified. Finally, the aggregated impact throughout the MTN is determined from the equations that describe the interrelationships of the individual MTN parameters. The following derivation shows how the MTN probability of occurrence values for the CITS-impacted configuration were computed in terms of (1) the parameter values that define the mid-1980s DAIS configuration without CITS, and (2) the impact of CITS as provided by R_s and R_f (CND improvement factors) values. The development of the R_s and R_f constitute the third step in the procedure to analyze the effect of mid-1980s innovative support system capabilities. This step will be explained later to avoid digression at this point.

The derivation begins by examining the basic MTN in more detail. Figure 4 is a sample MTN with per sortie probability of occurrence designations beneath the blocks. The following are definitions of the MTN parameters for the mid-1980s DAIS configuration. Primed symbols indicate those impacted by CITS.

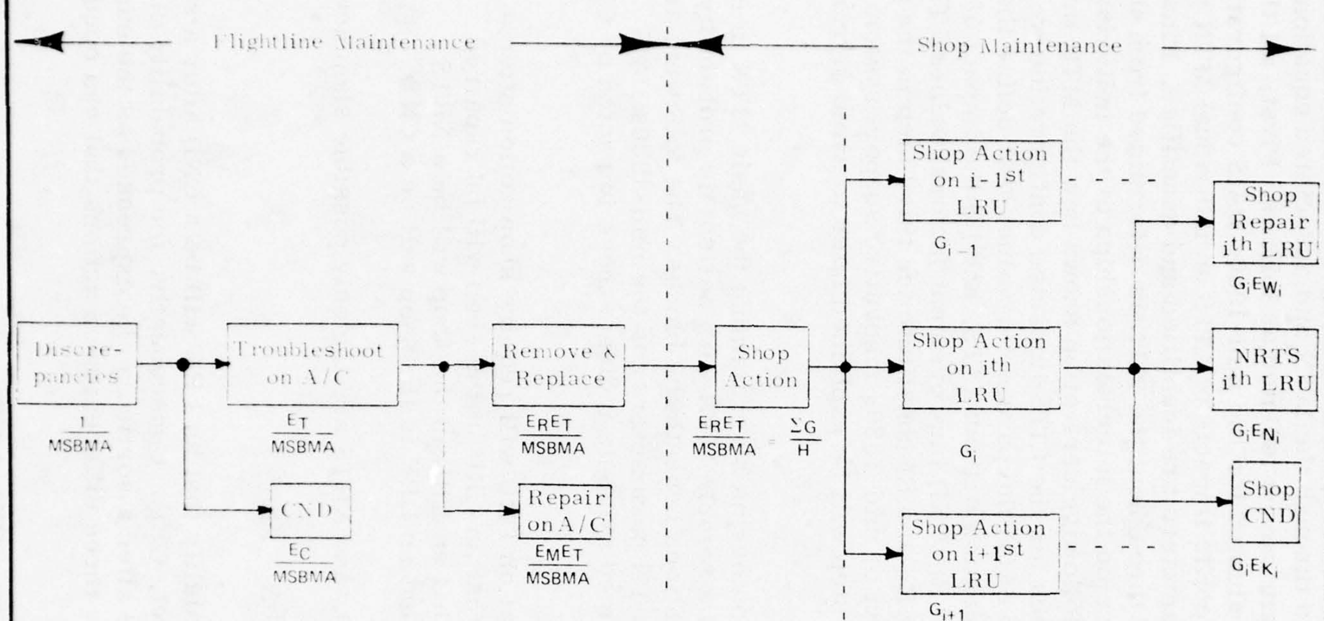
G = Probability that an LRU will require shop action after a sortie
E_W = Probability that an LRU in the shop will be repaired
E_N = Probability that an LRU in the shop will be a NRTS
E_K = Probability that an LRU in the shop will be a CND

Since repair, CND, and NRTS are the only possible shop actions,

$$E_W + E_N + E_K = 1 \tag{1}$$

Note that the probability that an LRU will be a CND after a sortie is equal to the product, GE_K. Consequently, the probability of a shop action taking place after a sortie can be expressed as the sum of the probabilities of the three different shop actions that can occur after a sortie.

$$G = GE_W + GE_N + GE_K$$



MAINTENANCE TASK NETWORK PROBABILITIES OF OCCURRENCES

Figure 4

The direct impact of CITS on shop actions is to reduce the occurrence of CNDs by a factor a, which results in fewer shop actions per sortie, G'. Therefore,

$$G' = GE_W + GE_N + GE_K a \tag{3}$$

In Table 8 (to follow), percentage reduction values are given for shop CNDs for each impact category. The impact category for each LRU is shown in Table 10 (to follow). The value used for a particular LRU is calculated as follows:

a) Determine the impact category from Table 10

b) Determine the appropriate shop CND reduction value from Table 8. Call this R_S.

c) $a = 1 - R_S$

The value of G' may now be computed in terms of G. In accordance with Eq. (1) substitute $(1-E_K)$ for $(E_W + E_N)$ in Eq. (3).

$$G' = [1-E_K\,(1- a)]\,G \tag{4}$$

or

$$\left[\frac{G}{G'}\right] = \frac{1}{1-E_K(1- a)} \tag{5}$$

The remaining shop task probabilities may now be determined. Rewrite Eq. (2) in terms of primed values to represent the result of adding CITS.

$$G' = G'E'_W + G'E'_N + G'E'_K \tag{6}$$

where E'_W, E'_N, E'_K are the probabilities of repair action, NRTS, and CND, respectively, for the CITS-impacted LRU.

Considering the probability of like events in Eq. (3) and (6) yields:

$$G'E'_W = GE_W$$
$$G'E'_N = GE_N$$
$$G'E'_K = GE_K a$$

or

$$E'_W = [\frac{G}{G'}] E_W$$

$$E'_N = [\frac{G}{G'}] E_N \qquad (7)$$

$$E'_K = [\frac{G}{G'}] E_K a$$

Equations (4) and (7) define the value of the shop probability parameters for the mid-1980s DAIS configuration as impacted by CITS.

Calculation of the impact on the flightline parameters proceeds in a similar manner.

Since the number of on-aircraft repairs per sortie does not change due to the addition of CITS,

$$\frac{E'_T \, E'_M}{MSBMA'} = \frac{E_T \, E_M}{MSBMA}$$

or

$$\frac{MSBMA'}{MSBMA} = \frac{E'_T \, E'_M}{E_T \, E_M} \qquad (8)$$

The number of shop actions per sortie, before and after the addition of CITS, is as follows:

$$\frac{E_T \, E_R}{MSBMA} = \Sigma \, G^{*} \qquad (9)$$

$$\frac{E'_T \, E'_R}{MSBMA'} = \Sigma \, G' \qquad (10)$$

---

* ΣG is actually $\sum_{i=1}^{n} G_i$ for a subsystem composed of n LRUs. This requires that the number of flightline removal actions be equal to the number of maintenance actions at the shop level. (This means that the "H" ratio shown in the "shop action block" of Figure 4 is equal to unity.)

The ratio of MSBMA' to MSBMA, using Eqs. (9) and (10) is as follows:

$$\frac{MSBMA'}{MSBMA} = \frac{E'_T\ E'_R}{E_T\ E_R}\left[\frac{\Sigma G}{\Sigma G'}\right] \qquad (11)$$

Equating Eqs. (8) and (11)

$$\frac{E'_M}{EM} = \frac{E'_R}{E_R}\left[\frac{\Sigma G}{\Sigma G'}\right] \qquad (12)$$

Since either a remove and replace action or an on-aircraft repair action is the only possible outcome of a troubleshooting action,

$$E'_R + E'_M = 1$$

or

$$E'_M = 1 - E'_R \qquad (13)$$

Substituting Eq. (13) into Eq. (12) yields:

$$E'_R = \frac{1}{1 + \frac{E_M}{E_R}\left[\frac{\Sigma G}{\Sigma G'}\right]} \qquad (14)$$

Similar to the reduction in shop CNDs, there is also a reduction in the probable number of flightline CNDs per sortie by a factor, β. β is defined as $1\text{-}Rf$, where Rf is determined from the subsystem impact category (Table 10) and the subsequent CND reduction factor of (Table 8).

$$\frac{E'_C}{MSBMA'} = \frac{\beta E_C}{MSBMA}$$

or

$$E'_C = \frac{MSBMA'\ \beta E_C}{MSBMA} \qquad (15)$$

The immediate outcome of a discrepancy write-up is either an on-aircraft troubleshooting action or a CND action,

$$E'_T + E'_C = 1$$

or

$$E'_C = 1 - E'_T \tag{16}$$

Substituting Eq. (16) into Eq. (15) yields:

$$E'_T = \frac{MSBMA - MSBMA' \, \beta E_C}{MSBMA} \tag{17}$$

Next, substitute Eq. (17) into Eq. (8), yielding:

$$MSBMA' = \frac{MSBMA}{\dfrac{E_M E_T}{E'_M} + \beta E_C} \tag{18}$$

Finally, substitute Eq. (18) into Eq. (15), yielding:

$$E'_C = \frac{1}{1 + \dfrac{E_M E_T}{\beta E'_M E_C}} \tag{19}$$

The results of this derivation are summarized in Table 6. These equations provide the means for determining the CITS impact on maintenance system demand.

Table 6

SUMMARY OF PROBABILITY EQUATIONS

Network Parameter	Value
G'	$G\,[1-E_K\,(1-\alpha)]$
E'_W	$[\frac{G}{G'}]E_W$
E'_N	$[\frac{G}{G'}]E_N$
E'_K	$[\frac{G}{G'}]E_K\,\alpha$
E'_R	$\dfrac{1}{1+\frac{E_M}{E_R}\,[\frac{\Sigma G}{\Sigma G'}]}$
E'_M	$1 - E'_R$
E'_C	$\dfrac{1}{1+\frac{E_T\,E_M}{\beta\,E'_M\,E_C}}$
E'_T	$1 - E'_C$
MSBMA'	$\dfrac{MSBMA}{\frac{E_M\,E_T}{E'_M} + \beta\,E_C}$
α	$(1-R_s)$, where R_s is the fractional decrease in shop CNDs
β	$(1-R_f)$, where R_f is the fractional decrease in flightline CNDs

Impact of Consolidated Support Equipment

Following the same approach as above, the impact of the consolidated SE was evaluated in terms of the potential influence on the parameters of the MTN. Analysis of the maintenance parameters indicates that SE will probably impact the following: bench test time portion of the bench test and repair tasks, number and skill level of maintenance personnel that perform the equipment bench checks, MSBMA, and probability of shop repair. These maintenance parameters were further analyzed using field data. It was determined that the bench test time and the number and skill level of the personnel performing the bench checks are the principal parameters impacted by the SE. This analysis and findings are discussed in the next section by actually quantifying these impacts. However, the last two influences (i.e.,MSBMA and probability of shop repair) derive from the fact that testing deficiencies often result in repeat flightline and shop CNDs for equipment that may, in fact, be malfunctioning. Although it was recognized that testing improvements could potentially reduce the occurrence of these CNDs and, thus, affect the probability of shop repair, further analysis indicated that the consolidated SE will probably not have a measurable impact on them.

SUPPORT SYSTEM IMPACT QUANTIFICATION

The second step of the general development of the MA, described in the preceding pages, has related the CITS and consolidated SE impacts to the MTN parameters. These maintenance parameters and their interaction are now examined. This constitutes the third step of the MA development to quantify the effects of the CITS and consolidated SE on maintenance task resource requirements.

There are essentially three basic techniques for accomplishing this: prediction, demonstration, and use of field data. The approach taken used a combination of all three, but selectively emphasized for each impact category the particular technique that provided the highest measure of confidence in the results.

Generally, the highest measure of confidence is obtained when actual data are available for the same or similar equipment under similar maintenance conditions. Next best, in terms of confidence, would be demonstration data gathered from the same equipment in a simulated (perhaps laboratory) environment. Third best is a prediction technique which uses estimates based upon analytical methods

and engineering judgment. Although it has the greatest margin of error, it must often be utilized when novel concepts or new systems are investigated. In the present analysis, the quantification of the SE impact relies most heavily on the field data technique while the CITS impact primarily utilizes that of prediction.

It was determined that two MTN parameters could be impacted by the SE. They are: (1) bench test time portion of the bench test and repair tasks and (2) number and skill level of maintenance personnel that perform the equipment bench checks. In order to quantify this impact it was necessary to select SE most appropriate for the current DAIS (used as a baseline) and the mid-1980s DAIS configurations, respectively. A combination of FB-111 and A-7D avionics SE was chosen for the baseline current DAIS configuration. The newest Air Force weapon systems are experiencing a trend towards test equipment consolidation. The F-15, among the latest, uses consolidated SE representative of what will probably be the norm in the mid-1980s, and was chosen for the mid-1980s DAIS configuration. Field maintenance data from it was utilized to quantify the bench test time portion of the bench test and repair tasks for the mid-1980s DAIS conceptual design configuration with consolidated SE.

In order to make a gross comparison of test times, weighted averages were computed on the basis of number of LRUs of interest tested on each station. In addition, shop CND time which is representative of one cycle of test time was estimated by dividing the test time only portion of the test and repair time by 1.5. This rule of thumb, developed on the basis of field interviews, was necessary because CND time is not directly recorded in available maintenance data records. The results given in Table 7 were obtained on the basis of this technique. They are encouraging because they indicate a potential 10 percent savings for manual test stations and up to a 50 percent savings for the computer controlled segment. These potential benefits at least partially define the impact that could occur when improved consolidated SE is utilized. However, before the MTN parameters were quantified for the mid-1980s DAIS configuration with consolidated SE, care was taken to insure the appropriateness of the data sets that were utilized.

A-7D data were utilized for the maintenance tasks associated with the sensor portion of the current DAIS configuration. To assess the MTN parameter impact for these tasks the specific times in the current DAIS MTNs were compared with field data obtained for the F-15 test stations on functionally similar LRUs. Analysis of the shop

Table 7

COMPARISON OF STATION TEST TIMES*

TEST STATIONS	FB-111			F-15			FB-111/F-15	
	Test & Repair	Test Only	Shop CND	Test & Repair	Test Only	Shop CND	Test & Repair	Shop CND
Manual	3.7	3.2	2.1	3.3	2.8	1.9	1.1	1.1
Semi-Automatic	4.3	3.8	2.5	–	–	–	–	–
Computer Controlled	4.5	4.2	2.8	3.2	2.9	1.9	1.4	1.5

Shop CND = $\frac{\text{Test Only}}{1.5}$ = One cycle of test time

*weighted averages based on the number of LRUs of interest tested on each station.

bench check and repair (W) and shop CND (K) task times revealed that the F-15 (W) and (K) task times were, in general, longer than those computed for the current DAIS configuration with current avionics SE. Therefore, a detailed engineering analysis was conducted to determine the cause.

The engineering analysis revealed that although the LRUs under comparison were functionally similar, they were not identical in design. The F-15 LRUs were in general more complex and required that an increased number of tests be performed to fault isolate and detect. This fact was the primary reason for the increased (W) and (K) times observed in the F-15 field data. Based upon further engineering assessment, it was concluded that the (W) and (K) times for the mid-1980s DAIS configuration would remain approximately the same as for the current DAIS configuration. Therefore the MTN parameters for the sensor portion of the configuration were not altered.

On the other hand, the SE test times for the mid-1980s DAIS core LRUs were reduced by 20 percent. This reduction factor was a conservative estimate based upon engineering judgment. The following reasoning was employed. The F-15 showed a 50 percent improvement (reduction in test time) over the FB-111 computer controlled automatic test station (ATS). Much of this is due to the transition from analog to digital systems within the aircraft which permit the more effective use of ATSs. Since the DAIS core elements are predominantly digital, a significant improvement can be anticipated. The conservative value of 20 percent was chosen as an initial projection for the mid-1980s, instead of the potential 50 percent, because of a number of offsetting factors which include: (1) the FB-111 showed a 10 percent higher test time than the existing current DAIS MTNs for the sensors, (2) some of the existing MTN task times are based on F-15 test stations' capability which already test LRUs with some digital circuitry, (3) the test time may increase when the F-15 test stations test "older" subsystems that have multiple faults.

In addition to the above test time reduction, consolidated SE has the potential for reducing the number of shop maintenance personnel required. Based upon information gained from field visits it was determined that in many cases the required number of technicians could be reduced from two to one. Exceptions occur when the test cables and fixtures required to hook up many of the LRUs are heavy, unwieldy and require two men to handle. Each of the shop maintenance

tasks was analyzed for the specific LRUs in the mid-1980s configuration. Reductions in shop maintenance personnel were postulated for the NRTS and CND tasks whenever feasible. However, the manpower requirements for the bench test and repair tasks were not altered due to the requirement of setting up equipment and on-the-job training.

The specific steps in quantifying the CITS impact on maintenance task resource requirements were: (1) quantify the impact on the demand placed on the maintenance system, (2) assess the impact on support maintenance task manpower requirements due to the potential for improved flightline testing, and (3) combine the results from steps (1) and (2) to compute the total impact on support maintenance task manpower requirements.

In order to obtain reasonable engineering projections, a group of twelve design and maintenance engineers was convened. Four rounds of questions were asked. After each round, responses were analyzed for consistency. Information was then fed back to the group and new questions were posed. After the final round the combined results were compiled for the group and then utilized to quantify the CITS impact on support maintenance task requirements. The major topics of the respective rounds were:

Round 1 - What are the major sources of errors in current avionics testing?

Round 2 - What is the magnitude of potential reduction in flightline and shop CNDs due to CITS?

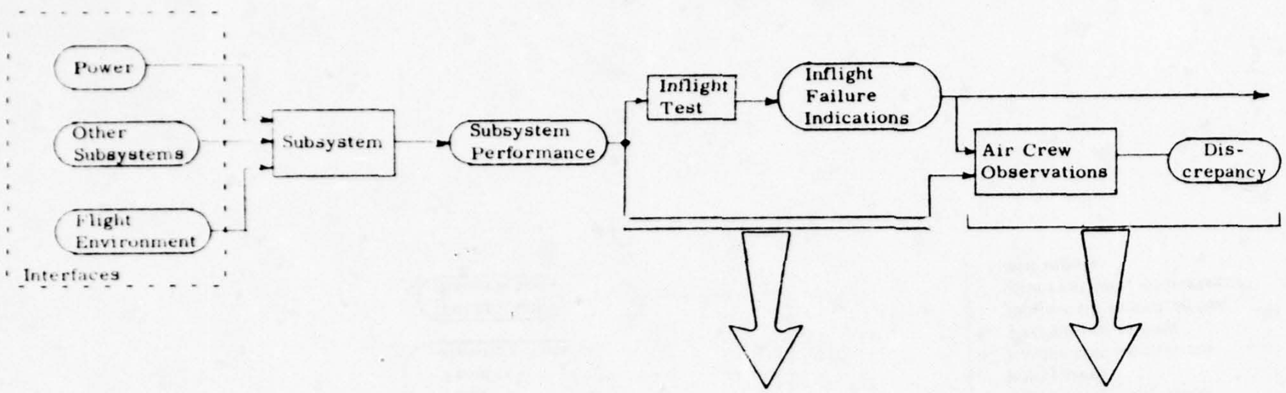
Round 3 - What CITS characteristics are the primary contributors to these CND reductions? What is the ranking of their importance?

Round 4 - Given the average of the group's results from the previous rounds, how should each of the subsystems and LRUs for the mid-1980s DAIS configuration be ranked?

The results of each round are discussed as follows.

As a result of the Round 1 activity, the representation of the test process and the potential sources of error for inflight and flightline testing can be summarized in Figures 5 and 6 respectively. The major maintenance impact is in terms of flightline and shop CNDs. The two major causes for both flightline and shop CNDs are limitations in test capability and excessive reliance on the judgment and experience of the maintenance technician (as a result of the test limitations).

Figure 5 INFLIGHT OPERATION AND TEST



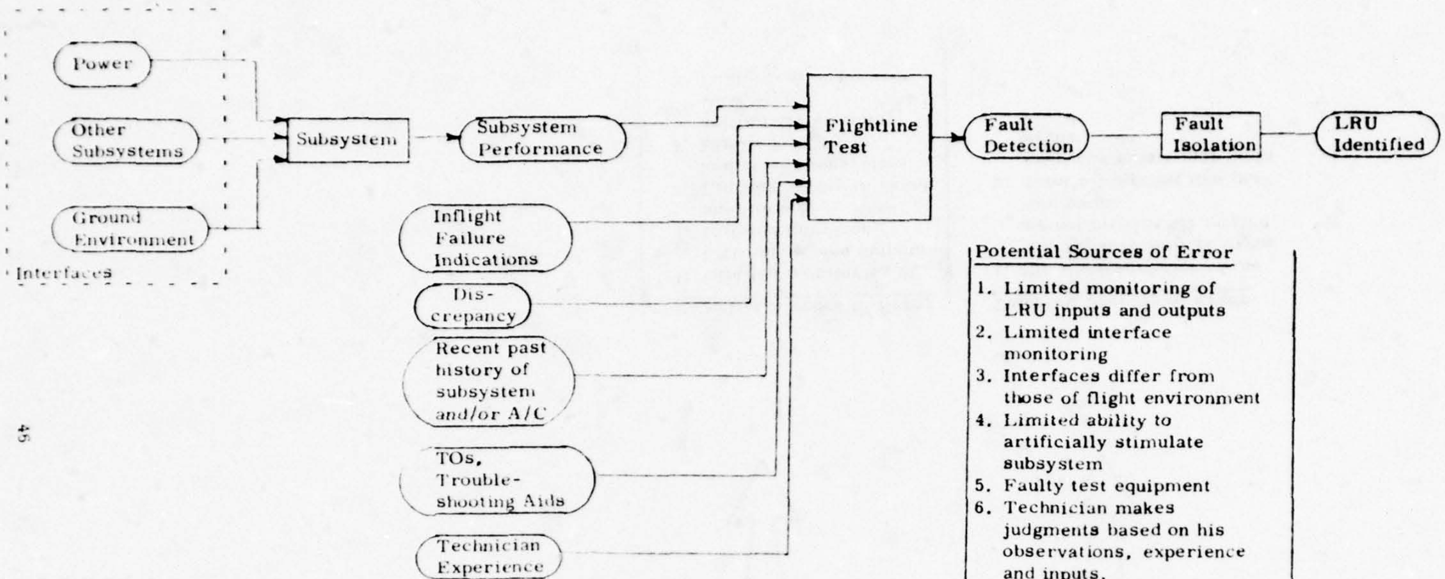
Potential Sources of Error

1. Limited monitoring of LRU inputs and outputs
2. Limited interface monitoring
3. Limited ability to reset and retest subsystem
4. Limited ability to artificially stimulate subsystem
5. Faulty test equipment

Potential Sources of Error

1. Pilot's description of the discrepancy may be vague or not provide all related symptoms.
2. Pilot's judgment that discrepancy exists may be in error

Figure 6 FLIGHTLINE TEST



Potential Sources of Error

1. Limited monitoring of LRU inputs and outputs
2. Limited interface monitoring
3. Interfaces differ from those of flight environment
4. Limited ability to artificially stimulate subsystem
5. Faulty test equipment
6. Technician makes judgments based on his observations, experience and inputs.

CNDs at the flightline come about because the discrepancy symptoms and/or the inflight test failure indications cannot be repeated during the flightline test. This may result from the following:

- The inflight malfunction was a temporary equipment failure or other equipment intermittent condition which has rectified itself; i.e., power interrupt, noise, etc.
- The inflight malfunction was caused by an interface problem not operative on the flightline; i.e., the offending subsystem may not be turned on during flightline test; loose connections to plugs and modules may be repaired as the result of other tests and repairs on the aircraft.
- The inflight malfunction was caused by an environmental factor which is not operative on the flightline. This could be a problem which would be difficult to find on the ground.
- The inflight discrepancy is the result of joint operation of marginally acceptable units. If one (or both) of these units is removed and sent to the shop, the result will be a shop CND since neither one is actually malfunctioning.
- The discrepancy description is inaccurate or incomplete.
- The operator may have made an error in the use of the equipment.
- The inflight test equipment is faulty.
- The flightline test equipment is faulty.
- The malfunction is caused by a software error.

Shop CNDs result from a different set of conditions. Some arise because of a policy that states that a discrepancy report on a critical subsystem requires corrective action. When the symptoms cannot be repeated on the flightline, the technician may remove and replace a LRU simply to allow the aircraft to return to service. However, the majority of shop CNDs result when the flightline test incorrectly identifies an operable system as having failed. When this event occurs, the flightline maintenance personnel will remove the LRU. Since the LRU is really operable, subsequent shop tests will result in a shop CND.

The specific causes of shop CNDs are:

- The discrepancy and/or test results implicate a subsystem other than the one actually malfunctioning. This comes about largely because of the various kinds and levels of equipment integration aboard the aircraft, i.e., common power sources and power supplies, common signals, one subsystem providing data inputs to another, etc. In the process of removing LRUs to repair the observed symptoms, the technician may remove several subsystem LRUs before he realizes that he is on the wrong track. Each operable LRU that is removed and sent to the shop subsequently becomes a shop CND.
- If the technician is led to the correct subsystem, he must still decide which LRU to remove based on his observations and experience. Due to the complexity of the subsystem, the maintenance technician's experience, and limited observational data, the wrong LRUs may be removed.

Policy also has another impact on shop CNDs. Based on operational readiness considerations, a policy decision is sometimes made to remove all LRUs that may be associated with a given failure. This will significantly reduce on-aircraft troubleshooting time and may place the aircraft back in service more quickly. It has the effect, however, of increasing shop CNDs.

The above information summarizes the results of Round 1. This summarized information was given to the group for their comment or concurrence. Then the group was asked to use the CITS characterization given in Tables 3 and 4 and to assess the magnitude of potential reduction in flightline and shop CND due to CITS. This formed the basis for Round 2. It was the group's consensus that the following considerations bound the problem.

a) CITS can have a significant impact in reducing CNDs by providing the additional information of which it is capable. However, since some reliance is still placed on the judgment of a technician, only a partial reduction is possible.

b) Shop CNDs are closely related to fault detection and fault isolation capabilities, while many flightline CNDs result from intermittent problems whose repeatability may be independent of the test equipment's capabilities. Therefore, the maximum potential impact on the shop CNDs is greater than that for the flightline.

With these considerations, the group then quantified the magnitude of the potential impact. The potential impact was divided into high, moderate, and low impacts because the specific impact would differ depending upon the particular subsystem or LRU under consideration. Estimates were examined for reasonableness and then averaged for each impact category. The group consensus is summarized in Table 8.

Table 8
CITS IMPROVEMENT LEVELS

Category	Potential CITS Improvement	
	Flightline CND Reduction (R_f)	Shop CND Reduction (R_S)
High	30%	50%
Moderate	20%	30%
Low	10%	10%

The group determined that the specific reduction of flightline and shop CNDs will depend upon the following CITS characteristics:

- improved ability to perform inflight verification testing
- the recording of inflight test results
- improved ability to perform active tests
- increased percentage of each unit tested
- improved LRU/SRU fault diagnosis capability

These considerations were then utilized to develop a CITS Impact Checklist in Round 3.

The objective in Round 3 was to provide a method for defining CITS impacts on CNDs at a level of lowest interaction by identifying small steps that require quantification. The group was asked to use the CITS characterization given in Tables 3 and 4 and to rank the five major CITS impact characteristics in terms of their relative importance. Estimates were examined for reasonableness and then averaged to form the group consensus. The CITS Impact Checklist given in Table 9 resulted.

In Round 4, the group of engineers was given (1) the CITS characterization (Tables 3 and 4), (2) the CITS improvement levels of Table 8, and (3) the CITS impact checklist of Table 9. The engineers were instructed to rank each subsystem and LRU in terms of these considerations. Estimates were examined for reasonableness and the group consensus was summarized in Table 10.

Using the results of these analyses the CITS impact on demand on the maintenance system was quantified. For each subsystem and LRU of the mid-1980s DAIS configuration the impact category of Table 10 was quantified using the values given in Table 8. Then specific values for the MTN parameters were computed for each subsystem and LRU by using the probability equations given in Table 6 with β equal to $1-R_f$ and α equal to $1-R_s$. This step completed the quantification of the CITS impact on demand on the maintenance system. The next step was to quantify the direct CITS impact on maintenance personnel.

Reduction in the number of required maintenance personnel is a fallout of the increased simplicity with which troubleshooting can be accomplished when a CITS is employed. The group was asked to quantify this impact. It was the consensus of the group that in many cases the number of maintenance personnel required for flightline troubleshooting and the remove and replace task could be reduced from two to one.

There were a few exceptions. Circumstances were found which tend to prohibit the full realization of the potential of CITS to reduce manpower. They occur when equipment is located in a relatively inaccessible portion of the aircraft requiring two men for its test or access, removal, and replacement; and one or more LRUs of the subsystem are too heavy to be lifted by one man. The subsystems within the mid-1980s DAIS configuration likely to be affected by these

Table 9

CITS IMPACT CHECKLIST

CITS Characteristics	Improvement	
	Flightline CND Potential Value	Shop CND Potential Value
Improved ability to perform verification testing	35%	15%
Recording of inflight test results	35%	10%
Ability to perform additional operational tests	20%	15%
Increased percentage of each unit tested	10%	30%
Improved LRU/SRU fault diagnosis capability	-	30%

Table 10

SUBSYSTEM AND LRU IMPACT CATEGORIES

Subsystem	LRU	Impact Category*
Navigation Instruments		L
Flight Instruments		L
HF Radio		M
	Receiver/Transmitter (R/T)	H
	Amplifier/Power Supply (PS)	H
	Antenna Coupler	H
	Variable Capacitor	H
VHF FM Radio		M
	R/T	M
	Antenna Coupler	L
Data Link		H
	R/T	H
	Mount and Antenna	L
UHF Radio		L
	R/T	M
	Standing Wave Ratio (SWR) Indicator	L
	Diplexer	L
UHF Automatic Direction Finder (UHF/ADF)		M
	Relay Amp	M
	Antenna	L
	Receiver	M
Intercommunications (IC)		L
	IC Set Control	L
	Station IC	L
	Audio Relay	L
IFF Transponder		H
	R/T	H
Speech Security		L
	Coder/Decoder	L
	Relay	L
TACAN		H
	R/T	H
	Antenna Switch	L

*H = High   M = Medium   L = Low

Table 10 (continued)

Subsystem	LRU	Impact Category
Instrument Landing System (ILS)		H
	Glideslope Receiver	H
	Antenna	L
Radar Altimeter		H
	R/T	H
	Interference Blanker	H
	Antenna	L
Radar Beacon		H
	R/T	M
	Antenna	L
Forward Looking Radar (FLR)		M
	Antenna/Transmitter	M
	Receiver	M
	Power Supply	M
	Mount/Other	L
Air Data Computer (ADC)		M
	Air Data Computer	M
	Probe	L
Inertial Measurement Set (IMS)		H
	Inertial Measurement Unit (IMU)	H
Heading Mode		M
	Rate Gyro	L
Radar Homing & Warning (RHAW)		H
	Signal Processor	H
	Receiver	H
	Amplifier/Detector	H
Strike Camera		L
	Camera	H
	Camera Pod	L
	Mount	L
	Electrical Control	H
Laser Target Identification (ID)		H
	Laser/Electro-Optics (EO)	M
	Gimbals/Pod	L

Table 10 (continued)

Subsystem	LRU	Impact Category
Forward Looking Infrared (FLIR)		H
	Infrared Receiver (IR)	H
	Power Supply	H
	Optical Stabilizer Pod	H
IR Tail Warning		M
	Search Track Scanner	L
Electronic Display Group		M
	Head-Up Display (HUD)	H
	Vertical Situation Display (VSD)	H
Display Controls		M
	Modular Programmable Display Gen.	H
	Display Switch/Memory Unit	H
Mass Memory Unit		H
	Electronic	M
	Magnetic Tape Transport Unit	M
	Control (MTTU)	M
Multifunction Controls		H
	Keyboard	M
	Control Panels	M
Dedicated Controls		H
	Power/Start Up Panel	M
	Armament Panel	M
	Communications Panel	M
	Entry Keyboard	M
	Master Mode Panel	M
	Sensor Controller	M
	Sensor Control Unit	M
Processor		H
	Computer	H
	Maintenance Control Panel	M
BCIU		H
RTU		H

exceptions are: the forward looking infrared (FLIR), the laser target identification (ID), the infrared (IR) tail warning, the strike camera, and the intercom.

The results of the foregoing analyses combined with those of the DAIS subsystem design change analysis provide the bases for assessing the impact of the mid-1980s DAIS configuration, CITS, and consolidated SE on support maintenance task resource requirements. Each of the impacts was quantified and then they were aggregated to determine the combined result. Maintenance task resource requirements were determined for the mid-1980s DAIS configuration with and without CITS and consolidated SE. It was determined that CITS and consolidated SE have the potential of reducing total manpower requirements by approximately 17 percent.

The resulting R&M data formed the basis for the mid-1980s DAIS MA data bank delivered to the Air Force Human Resources Laboratory at Wright-Patterson Air Force Base. This information was also utilized in the following section to analyze the results obtainable when the mid-1980s DAIS configuration with CITS and consolidated SE is utilized in a CAS aircraft.

III. ANALYSIS OF SYSTEM IMPACT

The following four configurations were addressed:

1. A conventional non-DAIS avionics suite
2. Current DAIS configuration
3. Mid-1980s DAIS configuration (without CITS and consolidated SE)
4. Mid-1980s DAIS configuration with CITS and consolidated SE.

It was recognized that a potential benefit in terms of overall service availability of the CAS avionics suite might accrue as a result of the mid-1980s DAIS configuration. This benefit was assessed by evaluating the configurations described above.

APPROACH

In order to evaluate the potential of the various configurations, it was first necessary to establish various criteria of goodness. These criteria are referred to as figures of merit. In terms of maintenance resource requirements, it was recognized that a meaningful measure was maintenance manhours per 1000 flight hours (MMH/1000 FH). It should be noted that MMH/1000 FH provides a basis for comparing subsystems within a given configuration to identify "high drivers" in terms of maintenance resource requirements. This information could presumably be fed back to design engineers to influence their design to reduce the maintenance requirements. Furthermore, when total MMH/1000 FH are computed for each configuration, comparisons between configurations can be made in terms of required maintenance resources. On this basis, configurations requiring fewer MMH/1000 FH can be judged as better than those with higher requirements. Therefore, our approach was to relate MMH/1000 FH to the maintenance parameters in the current and mid-1980s DAIS MTA data banks. The following relationship provides the means for computing the desired FOM.

$$\text{MMH per 1000 FH} = \frac{\text{MMH}_T \times 1000}{\text{MFHBMA}}$$

where MMH_T = total maintenance manhours expended per maintenance action

MFHBMA = mean flying hours between maintenance actions

RESULTS

Using the above expression and the R&M data from the appropriate MA data banks, values were computed for each of the subsystems in four configurations under investigation. The results obtained are given in Table 11. The values shown are the individual subsystem maintenance manhour requirements for each configuration. Notice that comparisons can be made for a specific subsystem in different configurations by reading numbers across columns. Comparisons between subsystems within a given configuration are made by reading down columns.

Subsystems were ranked in terms of their individual FOM and comparisons were made. (In this table, subsystems are ranked in terms of their maintenance manhour requirements for the mid-1980s DAIS configuration.) The individual values were then aggregated to determine the total system level MMH/1000 FH for each configuration as shown at the bottom of each column in Table 11.

The following discussion illustrates the type of analysis that can be performed using this information. The system level maintenance resource requirements are quantified in terms of the total MMH/1000 FH given at the bottom of each column. Comparisons can be made between the four configurations on a relative basis in terms of these values. On a total system basis the following conclusions result:

- When the mid-1980s DAIS design configuration with CITS and consolidated SE is compared to a conventional non-DAIS avionics suite, a reduction in total maintenance manhour requirements of approximately 47.1 percent is indicated in favor of the DAIS.
- The partitioning of the baseline non-DAIS subsystems to form the current DAIS conceptual design configuration accounts for approximately 21 percent of the indicated maintenance manhour reduction.
- Partitioning the subsystems specified for the mid-1980s DAIS conceptual design configuration accounts for a further reduction of approximately 9.6 percent.
- Incorporating CITS should reduce the required manhours by an additional 16.8 percent.

All percentages are referenced to an estimate of the manhour requirements of the conventional non-DAIS configuration. It must be emphasized that the above percentages reflect comparisons made on a relative basis. Although the computations have sometimes been expressed in terms of tenths of a percentage, these calculations are clearly not that precise because of the assumptions and approximations made in generating the data base. Nevertheless, on a relative basis these comparisons identify specific areas where benefits result.

The following discussion illustrates the type of analysis that can be performed on a subsystem basis using the information summarized in Table 11. If it is desired to determine which subsystems account for approximately half of the total maintenance manhour requirements, all that is needed to do is: (1) rank the individual subsystems in terms of MMH/1000 FH as was done in Table 11; and (2) sum the individual numbers until approximately 50 percent of the total requirement is found. This was done and it was noted that the combination of laser target ID set, FLIR, inertial measurement set (IMS), and forward looking radar (FLR) account for about half of the total maintenance manhours for each configuration. In terms of specific percentages, the MMH/1000 FH accounted for these four subsystems as follows:

non-DAIS baseline configuration	47.3%
current DAIS configuration	46.7%
mid-1980s DAIS configuration (without CITS and consolidated SE)	47.0%
mid-1980s DAIS configuration (with CITS and consolidated SE)	48.9%

The significance of this calculation is that it serves to focus the design and maintenance engineer's attention to areas where the largest potential payoff could accrue. If significant design changes could be identified that have the potential for reducing maintenance requirements, tradeoffs could be conducted using the total LCC modeling system to make selections on the basis of LCC.

Several potential design changes have already been identified in the course of this study; namely, the design changes associated with the various configurations under investigation. Their impact was assessed in terms of MMH/1000 FH by utilizing the information summarized in Table 11. The basis selected for comparison was the non-DAIS conventional avionics suite. Therefore, all percentage improvements refer to the maintenance requirements of that

Table 11

MMH/1000FH

Subsystem	Non-DAIS Baseline	Current DAIS	Mid-1980s DAIS w/o CITS/SE	Mid-1980s DAIS
		MMH/1000FH		
Laser Target ID	632.4	632.4	632.4	553.5
Forward Looking Infrared	452.7	452.7	452.7	401.9
Inertial Measurement Set	853.5	794.7	523.9	375.2
Forward Looking Radar	1068.2	472.8	472.5	311.5
Infrared Tail Warning	276.8	276.8	276.8	254.8
UHF Radio Set	246.5	196.7	176.3	150.4
HF Radio Set	291.0	245.2	245.2	133.5
Radar Altimeter	198.9	198.9	160.7	124.8
TACAN	224.8	220.3	144.9	117.0
Processor	N/A	146.3	146.3	108.8
Special Purpose Displays	N/A	159.4	159.4	107.5
Remote Terminal Unit	N/A	142.5	142.5	93.2
VHF-FM Communications	138.5	115.9	115.9	89.7
Air Data Computer	170.2	170.2	113.9	87.2
Flight Instruments	121.9	121.9	121.9	81.5
Mass Memory Unit	N/A	89.4	89.4	56.3
Radar Homing & Warning	79.3	62.0	62.0	47.8
Display Controls	N/A	78.9	78.9	47.6
Bus Control Interface Unit	N/A	69.8	69.8	44.4
Intercom	45.1	45.1	45.1	38.6
Radar Beacon Set	66.5	45.4	45.4	26.4
Speech Security System	40.0	28.1	28.1	18.7
Instrument Landing System	45.4	43.0	24.2	17.6
UHF Auto. Detection Finder	30.5	21.5	19.0	13.8
Strike Camera	13.6	13.6	13.6	11.8
Data Link	108.0	49.9	16.1	11.0
Navigation Instruments	14.2	14.2	14.2	10.5
IFF Transponder	74.0	52.9	11.4	9.5
Heading Mode System	111.9	58.3	7.5	4.8
Multifunction Controls	N/A	6.9	6.9	4.4
Electronic Displays	N/A	5.1	5.1	3.5
Dedicated Controls	N/A	5.6	5.6	3.5
Tactical Bombing Computer	427.4	absorbed by core		
Head-Up Display	529.4	absorbed by core		
Projected Map Display	95.3	absorbed by core		
TOTALS	6356.0	5036.4	4427.6	3360.7

configuration. Results are summarized in Table 12 for the subsystems identified as the major consumers of manpower. The first column in Table 12 shows the percentage reduction in MMH/1000 FH resulting from the current DAIS architecture. The second column highlights the additional percentage reduction in MMH/1000 FH that could be realized by the technology advances projected for the mid-1980s DAIS architecture. The final column identifies the total percentage improvement that could be realized when the mid-1980s DAIS is coupled with CITS and consolidated SE.

Note: Both the laser target ID and the FLIR are pod-mounted. As such, they were not partitioned and therefore show no improvement between the non-DAIS baseline, current, and mid-1980s DAIS configurations. However, the incorporation of CITS in the mid-1980s configuration results in a measurable benefit for these subsystems.

An overall reduction of 49.1 percent in MMH/1000 FH was indicated for the IMS in going from the current DAIS to the mid-1980s DAIS design with CITS and consolidated SE. This reduction is the result of: (a) specification of the AN/ASN-109 as the IMS for the mid-1980s configuration; and (b) incorporation of CITS and consolidated SE to provide improved flightline and shop testing. These rather dramatic effects may be explained as follows:

a) The IMS used in the current DAIS conceptual design configuration is the AN/ASN-90. Partitioning this subsystem resulted in two sensor LRUs, i.e., the inertial measurement unit (IMU) and adapter/power supply. The AN/ASN-109, used in the mid-1980s configuration contains only one sensor LRU, i.e., the IMU. The shop and flightline manhours are reduced by 31.7 percent due to the elimination of the adapter/power supply.

b) The incorporation of CITS and consolidated SE further reduces the manhour requirements associated with the IMU by 17.4 percent for the following reasons:

   - Fewer flightline technicians are needed for the troubleshooting and remove and replace tasks. The reduction is from two men to one.
   - As described in Section II, CITS effectively reduces the demand in the maintenance system because CNDs are reduced for the IMU.

Table 12

MMH IMPROVEMENTS FOR HIGH DRIVER SUBSYSTEMS

Sub-System	Percent Improvement Due to *		
	Current DAIS Architecture	Mid-1980s DAIS Architecture	CITS and Consolidated SE
Laser	-	-	12.5
FLIR	-	-	11.2
IMS	6.9	31.7	17.4
FLR	55.7	0.0	15.1

*All percentages are with reference to the non-DAIS baseline.

- For the IMU, consolidated SE results in the reduction of shop personnel from two to one for the CND and NRTS tasks.
- These reductions of the number of flightline and shop personnel, producing a manhour reduction of 13.2 percent, are compounded by an additional manhour reduction due to the decreased number of CNDs which amounts to 4.2 percent.

For the FLR, the major impact is due to the partitioning of the non-DAIS baseline systems to form the current DAIS FLR design. Of the original 11 LRUs comprising this subsystem, 5 were transferred to the core elements resulting in large improvements in: (a) average shop and flightline maintenance manhours per discrepancy report; and (b) MSBMA, culminating in lowered total maintenance demand. The additional 15.1 percent reduction for the mid-1980s DAIS FLR is an effect of the same factors described above for the IMS. The mid-1980s FLR is based on the LRU configuration of the AN/APG-63 used on the F-15. No provision exists in that equipment for a radar fault location set, an LRU that exists in the current DAIS FLR. However, the effect of this in reducing demand on both the flightline and shop is insignificant. The introduction of CITS and consolidated SE provides the bulk of the 15.1 percent reduction in manhours estimated to be a result of its use in the mid-1980s DAIS configuration.

Other comparisons of this type could easily be made for each of the subsystems listed in Table 11. Results of this initial analysis illustrate one of several ways in which the FOM methodology could be used to obtain useful information which could be fed back to the design engineer to influence his selections during the tradeoff process. However, before a final selection is made, the total proposed system should be analyzed using the entire LCC modeling system. (This step will be accomplished later in the DAIS LCC study upon completion of the modeling system development.)

It was recognized that the mid-1980s DAIS will probably yield a potential benefit in terms of the overall service availability of a CAS avionics suite. Service availability (A_S) is defined as that measure of overall system availability which is obtained by multiplying all the independent subsystem inherent availabilities; i.e.,

$$A_S = A_1 \times A_2 \times \ldots \times A_j$$

where A_j = inherent availability of j^{th} subsystem

Subsystem inherent availability is defined as the fraction of time that an aircraft subsystem is available for flight based on the reliability and the flightline maintenance needs of that subsystem. (It is assumed for this calculation that all subsystems and LRUs removed from the aircraft are immediately replaced. Thus, stockouts or any other delays in obtaining spares are not included in this evaluation.) The equation used to compute the inherent availability of each subsystem is:

$$A_j = \frac{MFHBMA_j}{MFHBMA_j + MTTR_{F_j}}$$

where

MFHBMA = Mean Flight Hours Between Maintenance Actions
$MTTR_F$ = Mean Time to Repair at the Flightline

Inherent subsystem availability values for the design configurations under examination are shown in Table 13. Their ranking is based on an ordering of the A_j values that result for the mid-1980s DAIS conceptual design configuration. Once again, the laser target ID, FLR, FLIR, and IMS seem to be the subsystems that exert the major impact on the service availability of the total avionics system. A service availability value was obtained by taking the product of the individual A_j values of subsystems within each particular design configuration. For comparative purposes a summary of these values and the percentage improvements relative to the conventional non-DAIS baseline configuration are given in Table 14.

Two major assessments have been carried out in this section. First, the maintenance task manpower requirements were determined for the following configurations:

1. A mid-1980s DAIS configuration with CITS and consolidated SE
2. A mid-1980s DAIS configuration without CITS and consolidated SE
3. A current DAIS configuration, and
4. A conventional non-DAIS avionics suite.

It was determined that the mid-1980s DAIS configuration resulted in a 47.1 percent reduction in total MMH/1000 FH when compared with a conventional non-DAIS avionics suite.

Next, the impact of the mid-1980s DAIS configuration on the service availability of the CAS avionics was assessed. On the basis of aircraft flightline availability a 74.3 percent improvement resulted when the mid-1980s DAIS configuration was compared with a conventional non-DAIS suite.

Table 13

INHERENT AVAILABILITY BY SUBSYSTEM

Subsystem	Mid-1980s DAIS With CITS/SE	Mid-1980s DAIS Without CITS/SE	Current DAIS	Non-DAIS Baseline
Laser Target ID	.8515	.8407	.8407	.8407
Forward Looking Radar	.8747	.8703	.8703	.7572
Forward Looking Infrared	.8778	.8705	.8705	.8705
Inertial Measurement Set	.8859	.8724	.8278	.8138
Infrared Tail Warning	.9353	.9341	.9339	.9339
Flight Instruments	.9470	.9459	.9459	.9459
Processor	.9526	.9490	.9488	N/A
HF Radio	.9645	.9618	.9618	.9494
TACAN	.9662	.9654	.9510	.9490
UHF Radio	.9675	.9671	.9627	.9341
Air Data Computer	.9703	.9689	.9599	.9599
VHF-FM Communications	.9703	.9687	.9687	.9655
Radar Altimeter	.9713	.9675	.9571	.9571
Special Purpose Displays	.9725	.9700	.9699	N/A
Remote Terminal Unit	.9756	.9743	.9744	N/A
Mass Memory Unit	.9763	9758	.9758	N/A
Radar Homing & Warning	.9819	9805	.9805	.9730
Intercommunications	.9858	9856	.9840	.9840
Radar Beacon Set	.9874	.9871	.9870	.9764
Speech Security System	.9876	.9876	.9876	.9822
Display Controls	.9887	.9875	.9875	N/A
Bus Control Interface Unit	.9891	.9877	.9877	N/A
Instrument Landing System	9922	.9912	.9833	.9816
UHF Auto. Direction Finder	.9930	9927	.9919	.9906
Navigation Instruments	.9947	.9947	9947	.9947
Strike Camera	.9951	.9946	.9946	9946
Data Link	.9960	.9929	.9786	.9654
IFF Transponder	.9966	.9964	.9835	.9762
Heading Mode System	.9966	.9965	.9720	.9557
Multifunction Controls	.9984	.9983	.9981	N/A
Dedicated Controls	.9984	.9984	.9984	N/A
Electronic Displays	.9990	.9990	9989	N/A
Tactical Bombing Computer	absorbed by core			.9055
Head-Up Display	absorbed by core			.9115
Projected Map Display	absorbed by core			.9723

Table 14

SUMMARY OF
SERVICE AVAILABILITY BY SYSTEM

Configuration	Service Availability Value	Service Availability x 100%	% Service Availability Improvement over non-DAIS Baseline Configuration
Non-DAIS baseline	.1899	19.0%	-
Current DAIS	.2634	26.3%	38.7%
Mid-1980s without CITS	.3078	30.8%	62.0%
Mid-1980s with CITS and consolidated SE	.3310	33.1%	74.3%

Note that these service availability values have no relevance in the "real world" since multiple failures occur and their maintenance is actually carried out simultaneously. The values shown are to be viewed as figures of merit for the design configurations listed and are valuable for comparisons only.

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GLOSSARY OF ACRONYMS

A	availability
A/C	aircraft
ADF	automatic direction finder
ADI	attitude direction indicator
AFAL	Air Force Avionics Laboratory
AFHRL	Air Force Human Resources Laboratory
AFLC	Air Force Logistics Command
AFSC	Air Force specialty codes
ATC	action taken code
ATS	automatic test station
BCIU	bus control interface unit
BIT	built-in test
BITE	built-in test equipment
CAS	close air support
C/D	controls and displays
CITS	central integrated test system
CF	CITS improvement factor
CND	cannot duplicate
DAIS	digital avionics information system
DAIS ADP	DAIS advanced development program
DRC	Dynamics Research Corporation
E	mutually exclusive probability
ECM	electronic countermeasures
EDB	engineering data base
EO	electro-optics
FH	flight hours
FLIR	forward looking infrared
FLR	forward looking radar
FM	frequency modulation
FOM	figure of merit
GPTE	general purpose test equipment
HF	high frequency
HSI	horizontal situation indicator
HUD	heads-up display
IC	intercom
ICS	intercommunications system
ID	identification
ILS	instrument landing system
IMA	intermediate maintenance level (shop) activities
IMS	inertial measurement set
IMU	inertial measurement unit
IR	infrared
JPA	job performance aids

K	shop CND
K_d	degradation factor
K_m	ratio of unscheduled maintenance actions to actual failures requiring shop action
KMA	number of bench check OK (shop CND) maintenance actions
LCC	life cycle cost
LCOM	logistics composite model
LRU	line replaceable unit
LSC	logistics support cost
MA	maintenance analysis
MA_T	total maintenance actions
MADAR	malfunction analysis detection and recording system
MDC	maintenance data collection
MDCS	maintenance data collection system
MFHBMA	mean flight hours between maintenance actions
MI	maintenance index
MMA	maintenance actions performed on the flight line
MMH	maintenance manhours
MMH/ATC	maintenance manhours per action taken code
MMH/FH	maintenance manhours per flight hour
MMH/MA	maintenance manhours per maintenance action
MMMS	maintenance manpower modeling system
MSBF	mean sorties between failures
MSBMA	mean sorties between maintenance actions
MTBF	mean time between failures
MTBMA	mean time between maintenance actions
MTN	maintenance task network
MTTR	mean time to repair
MTTU	magnetic tape transport unit
N	shop not repairable this station task
NAVAIR	Naval Air Systems Command
NMA	number of bench check and NRTS maintenance actions
NRTS	not repairable this station
OH	operating hours
O&M	operation and maintenance
PS	power supply
QPA	quantity per aircraft
R_I	inherent reliability
R_O	operational reliability
R&M	reliability and maintainability
RMA	number of flightline remove and replace maintenance actions
R/T	receiver/transmitter
RTOK	retest OK
RTU	remote terminal unit

SE	support equipment
SPO	system project office
SRU	shop replaceable unit
SWR	standing wave ratio
TAT	turn around time
TCTO	time compliance technical order
TO	technical order
TOA	table of allowances
UHF	ultra high frequency
USAF	United States Air Force
VHF	very high frequency
VSD	vertical situation display
W	shop repair task
WMA	number of bench check and repair maintenance actions
WUC	work unit code

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